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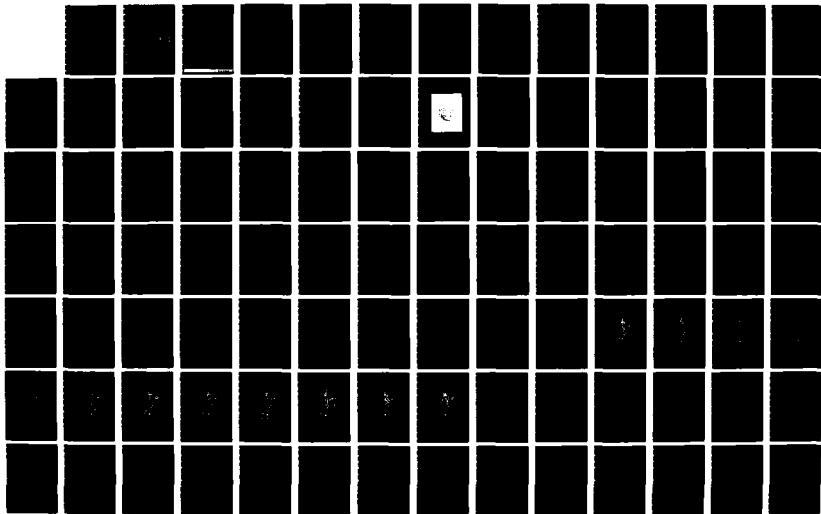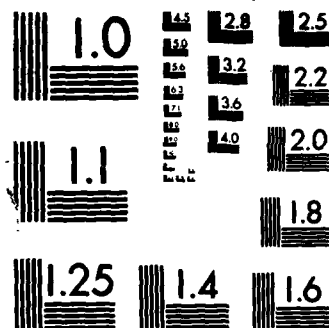   WRIGHT-PATTERSON AFB OH   E W DOBRY 1986

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ABSTRACT

A Global Solar Irradiance Climatology of an Intermountain Region

by
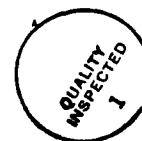
Eugene W. Dobry, Jr., Master of Science

Utah State University, 1986

Major Professor: Dr. G. E. Bingham
Department: Soil Science and Biometeorology

A global solar irradiance climatology of an intermountain region
is developed using radiation data from ten measurement stations that
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prepared based on data collected from 1981-1984. Monthly and
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skewed frequency distribution. The median statistic is considered
more realistic than the mean for determining the average value of
these time periods. Daily averages are presented on monthly maps
showing the temporal solar energy distribution in Utah. Non-
homogeneous terrain significantly distorts the normal latitudinal
distribution pattern of irradiance. Effects on weather by the
Great Salt Lake and Wasatch Mountain Range are discussed.

(95 pages)

A GLOBAL SOLAR IRRADIANCE CLIMATOLOGY OF AN INTERMOUNTAIN REGION

by

Eugene W. Dobry, Jr.

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Soil Science and Biometeorology
(Biometeorology)

UTAH STATE UNIVERSITY
Logan, Utah

1986

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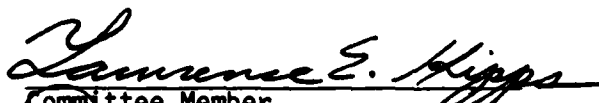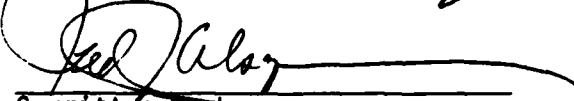of the requirements for the degree

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ABSTRACT

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INTRODUCTION

The sun is the earth's ultimate energy source. Its presence is essential for life to exist on the planet and is the primary driving force for the earth's natural systems. Our sun orchestrates the weather and indirectly powers the world's ocean currents. Plants take advantage of the abundant energy to manufacture their food. Man, however, uses this energy source directly in a relatively limited capacity.

Since the industrial revolution, our energy needs have been met almost entirely by using stored solar energy in the form of fossil fuels. Coal and oil have been less expensive, more efficient and easier to convert into our needed energy forms, i.e., heat, steam and electricity. Because of these facts, developing ways to harness solar energy has had little incentive. This was true until the petroleum energy crisis of the 1970's. Since then, the economic advantage of fossil energy has diminished and surges in interest and research have occurred in the application of solar energy.

The sun's radiant energy reaches all parts of the earth's surface, but it is not evenly distributed and varies greatly with time and space. This radiation has an impact on most of man's endeavors including: agriculture, architecture, climatology, energy consumption, forestry, meterology, oceanography and transportation. To effectively understand and exploit this energy source, information on its nature and distribution is needed by researchers and workers

in these and other fields. For example, the characteristics of solar radiation are of great importance in the design and determination of energy usage in buildings. In agriculture, solar information is crucial for accurate evapotranspiration calculations and crop production estimates. Also in solar energy conversion projects, irradiance measurements and analysis are a prerequisite for determining the utilizability and effectiveness of the systems. These are just a few of the many reasons why knowledge of the availability of solar radiation in different regions is important and needs to be studied.

In 1980, the Department of Energy (DOE) determined that the existing nationwide solar measurement network failed to accurately quantify the solar resource for over 80 percent of the State of Utah. They negotiated a contract with Utah State University to collect additional solar irradiance data in Utah and in 1981 a monitoring network of ten stations was established (Table 1). Site locations were selected that could accomplish two objectives: achieve good spatial coverage of the state, and benefit the populated areas by providing immediate data usage for solar energy utilization (Dept. of Soil Science and Biometeorology and Ecology Center, 1982).

Yearly data from these stations has been tabulated into listings but no statistical analysis or assessment of the data had been performed. This study is a preliminary analysis on the Utah Solar Network data set. This data set will be used to study the influence of the choice of time scale and central tendency measure on the analysis of solar energy amount and distribution in a heterogeneous region. It is felt that information contained in this

Table 1. Utah solar irradiance network stations

Station Location	Latitude	Longitude	Elevation
Logan, UT 　　Natural Resources building roof	N 41°45'	W 111°50'	1,490 m / 4888 ft
Salt Lake City, UT 　　Airport Executive Terminal building roof	N 44°46'	W 111°58'	1,290 m / 4232 ft
St. George, UT 　　Dixie College building roof	N 37°06'	W 113°34'	880 m / 2887 ft
Cedar City, UT 　　SUSC Science Center elevator shaft roof	N 37°40'	W 113°04'	1,770 m / 5807 ft
Delta, UT 　　High school roof	N 39°21'	W 112°34'	1,420 m / 4659 ft
Lucin, UT 　　Exposed rise	N 41°20'	W 113°54'	1,400 m / 4593 ft
Altamont, UT	N 40°22'	W 110°17'	1,980 m / 6496 ft
Ferron, UT 　　Open field	N 39°05'	W 111°08'	1,820 m / 5971 ft
Fontenelle Dam, WY 　　Moved to	N 42°00'	W 110°04'	2,010 m / 6594 ft
Kemmerer, WY	N 47°41'	W 33°110'	2,190 m / 7185 ft
Grace, ID 　　High school roof	N 42°34'	W 111°44'	1,700 m / 5577 ft

thesis will benefit individuals who use or plan to use this energy source.

Main Objective

The purpose of this study is to provide information on the temporal and spatial characteristics and availability of the incident total or global solar irradiance in an intermountain region as measured by the Utah Solar Network.

Specific Objectives

1.   Examine whether the median statistic is more realistic than the mean in expression central tendency for solar data in this region.

2.   Determine if using a shorter time interval in data analysis or in reporting of statistics provides more description of temporal variability in solar irradiance.

3.   Assess the global solar irradiance distribution of the region.

LITERATURE REVIEW

The measurement and analysis of solar radiation has a brief and questionable history. This is due to the limited quantity and quality of data available and the use of controversial statistics in the data analyses. Data summaries from 1952 to 1975 have been published in the Insolation Data Manual (Knapp et al., 1980). These data have also been presented in an Atlas (SERI, 1981). These manuals contain summaries for 248 National Weather Service (NWS) stations of which 221 are located in the conterminous United States. Actual measurements of solar radiation energy were taken at only 26 stations. The remaining non-measurement stations contain summaries of tabulated modeled data determined from other meteorological parameters. None of the measurement stations are located in Utah. The closest one is located at Ely, Nevada.

Because of the limited number of recording stations, these manuals can, at best, only estimate the large scale distribution of solar energy. They are of little use when attempting to determine the availability of solar energy for locations that are not near a reporting station. Also, interpolation of data in non-homogeneous geographic locations creates even more significant errors because the grid density is too sparce to detect differences in solar irradiance caused by terrain induced "local" weather. In 1977, the National Oceanic and Atmospheric Administration (NOAA) through the National Weather Service increased the number of

measurement stations to 35 providing better coverage. But, this still is considered inadequate to accurately assess the radiation climate for all areas of the country (Suckling, 1982). One such area deficient in coverage is the intermountain region which includes the State of Utah. This part of the country has been classified on a global scale (Terjung, 1970 and Löf et al., 1966) as an area that receives abundant solar radiation. Although the southern part of the region is considered as part of the United States sunbelt, climatic data infer that strong spatial gradients exist. These gradients result from large variations in geographic, atmospheric and terrain conditions. Researchers documenting the radiation climates of our country have found this area difficult to classify (Vernon, 1979; Willmott and Vernon, 1980; and Balling and Vojtesak, 1983). Willmott and Vernon (1980, p. 300) state, "the mountainous physiography exerts highly variable influences on solar radiation making interpretations difficult."

A few mountain irradiance studies have been conducted in recent years to determine factors that affect solar radiation (Dirmhirn, 1982; Mohr, 1981; Secrest, 1980, and Sa Diniz, 1978). What these researchers have determined is that solar irradiance is modified by: elevation, reduced path length of solar rays through the atmosphere, thinner clouds and multiple reflections from the terrain and snow cover. Differences in total solar irradiance were discovered in each of these areas: mountain-valley relationships, east-west slope orientations and from the seasonal availability of sunshine. They reached conclusions that mountainous areas have very complicated radiation environments and advise caution in making over generalizations for these areas.

Many statistical studies have been conducted on solar data from other regions, such as: the north-central region of the U.S. (Baker and Klink, 1975), North America (Bennett, 1967), selected U.S. cities (Garrison, 1984), an equatorial region, Singapore (Goh, 1979) and from various small countries (Khogali et al., 1983; Kudish et al., 1983; Scerri, 1982; and Sfeir, 1981). All of these studied calculated daily averages and determined the variability of solar energy values for selected time intervals. Most of them calculated the mean and standard deviation for their statistic measurements. Only two (Bennett, 1967; and Baker and Klink, 1975) examined the frequency distribution of the data and in both cases they decided to use different statistics to determine averages and variability. Bennett (1967) remarked at length about the fact that frequency distributions of daily insolation values are seldom normal. In his analysis he discovered the frequency distributions to be generally skewed. He recommended not using the arithmetic mean as an indicator of probable values because it can lead to serious errors. Instead, he suggested using the median to accurately determine the 50% probability level. He also mentioned that the median cannot replace the mean when an estimate of the total insolation for a period is desired.

In the north-central region study (Baker and Klink, 1975) radiation data from 15 stations were analyzed. They examined weekly distributions of daily radiation values and found this period also exhibits distributions that are generally skewed and occasionally bimodal. Skewness was less pronounced during the low sun period (winter) because of lower solar itnensity, short days, and an increase in cloud cover.

More recent researchers have specifically concentrated on the statistical nature of radiant energy (Mustacchi et al., 1979; Engels et al., 1981; and Skaggs et al., 1982). These investigators all found probability distributions to be non-Gaussion. Skaggs et al. (1982) analyzed a 17-year period of global radiation measurements and concluded that monthly frequency distributions were bimodal, a result of years that were predominantly cloudy and years that were predominantly clear.

MEASUREMENT UNITS

The International System of Units (SI) is used in this study. Solar radiation values are expressed in kilojoules (KJ)/square meter (m²) or KJ/m² and Megajoules (MJ)/square meter or MJ/m². One megajoule equals KJ x 10³. The solar radiation contour maps depict the amount of energy (solar radiation) incident on one square meter per day.

The depicted energy values represent an average daily value for that particular month. The daily value is the amount of energy accumulated from sunrise to sunset.

Other solar radiation energy units are used within the solar community. The conversions of the (SI) units to these are as follows (List, 1966):

$$41.856 \text{ KJ/m}^2 \quad = 1 \text{ langley}$$
$$= 1 \text{ gram cal/cm}^2$$
$$= 3.688 \text{ BTU/ft}^2$$
$$= .0116 \text{ KWhr/m}^2$$

The basic time units used in the study are the calendar month and the climatological week. The climatological week is used instead of the calendar week because the day and week number remain the same regardless of whether there is a leap year. Week 1 is the week of March 1-7 and week 52 is February 21-27. Week 53 which includes February 28 and 29 is omitted from consideration.

SITES, INSTRUMENTATION AND METHODS

The data used in this study are daily "total" or global solar radiation values for calendar years 1981-1984 as measured from ten stations that comprise the Utah Solar Network. Two stations (Altamont, Utah and Lucin, Utah) contain only two (1983-1984) and three (1981-1983) years of data, respectively. The name, location and elevation of each of the measurement stations are given in Table 1. The station at Fontenelle, Wyoming, was moved in January, 1983 to Kemmerer, Wyoming. Since these two stations are less than 20 miles apart and have similar terrain features, it was assumed that the radiation received at each location did not significantly differ (Suckling, 1982) and their records were combined to produce a single four-year record. A more detailed description of each site is published elsewhere (Bingham et al., 1985).

The instrumentation at each recording station consisted of two star pyranometers placed on a specifically designed stand, a 12 VDC powered microdata logger, a cassette recorder and two strip chart recorders (one for each pyranometer) as a back-up system. One pyranometer detected global radiation on the horizontal plane and the other one detected diffuse radiation with the aid of a shadow band.

Irradiance measurements were made using the Schenk, black and white star pyranometer. See Figure 1. The pyranometer measures
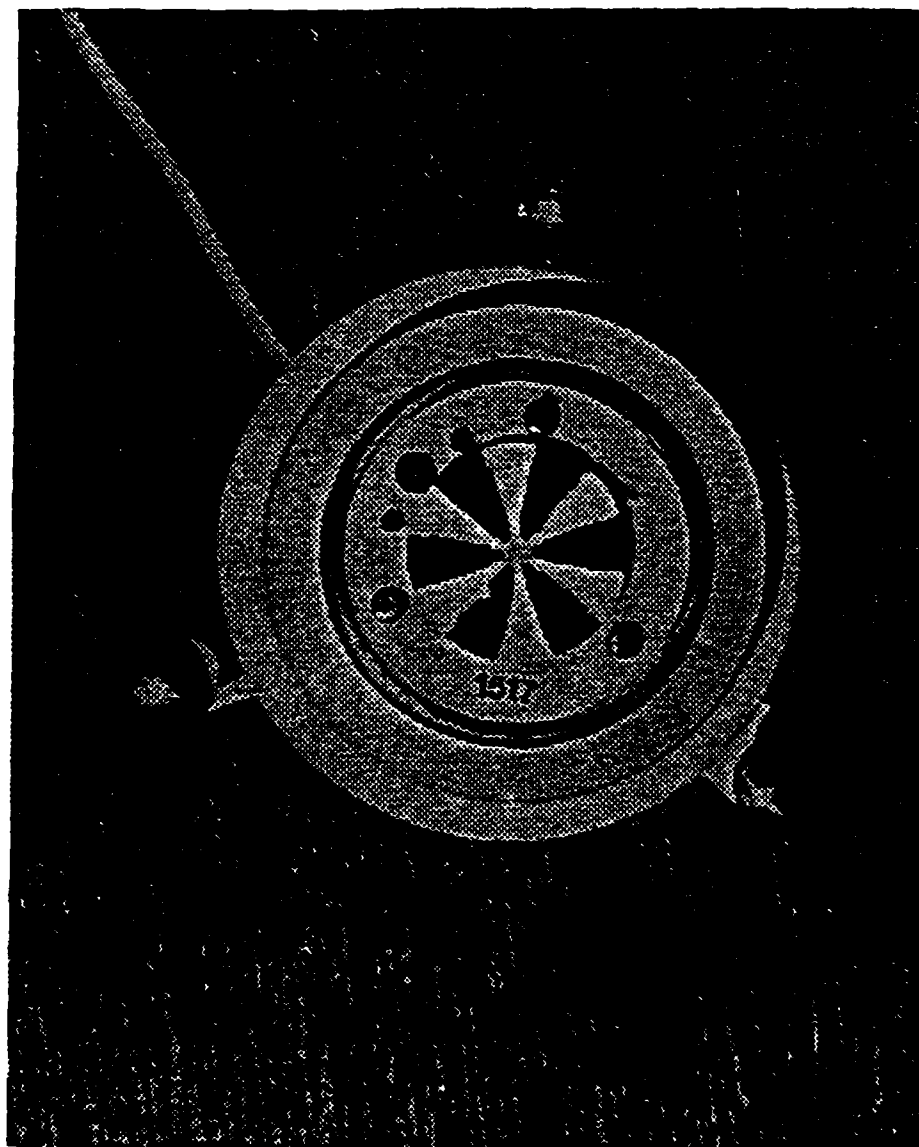
Figure 1. Black and white star pyranometer used in the
Utah Solar Network.

global radiation in the wavelength range of 0.3-3.0 μm. The pyranometers were connected to a microdata logger and in parallel to a stripchart recorder. The data logger was either a CR5 or CR21 manufactured by Campbell Scientific, Logan, Utah. The CR5 data logger system contained several modules which performed specialized functions and was housed in a metal suitcase type container. A control module acted as a clock recording the day, hour, and minute of a data sample. It was also used to set the data sampling interval. The data loggers sampled the sensor outputs, integrated the millivolt signal over a 15 minute period, and temporarily stored the data. A tape interface module was used to transfer the data from digitized electronic impulses to audible pulses stored on cassette tapes. Each cassette tape held 14 days of data, consisting of 15 minute averages of global and diffuse radiation measurements.

The stripchart recorders (Model SR705) were manufactured by Datamart. One recorder was connected directly to each pyranometer, parallel to the data logger. They served as a back-up system and provided a method of verifying the data collected by the data logger system.

The instruments were visited regularly by volunteer operators who cleaned the pyranometer domes, adjusted shadowbands, and performed recorder function checks. Periodically (not less than twice each year) each instrument was thoroughly inspected by a technician from Utah State University. During this inspection a comparison calibration was performed with a secondary standard pyranometer held in reserve to determine calibration shifts with

time. These error corrections were incorporated into the data
during the editing process.

Because of occasional malfunctioning equipment or occurrences
of snow, ice, or heavy frost on an instrument dome, there were days
or portions of days for which data was unavailable. In some cases,
the back-up stripchart could be used to recover the missing or bad
tape data. These data were manually reconstructed during the
editing process. Much more of the diffuse data were unrecoverable
because operators failed to adjust the shadowbands. As a result of
a large quantity of missing data, only the global irradiance data
will be analyzed in this study.

The editing process was accomplished in a series of steps.[1]
The data were first transferred from magnetic cassette tape to floppy
disks. The next step consisted of displaying each day's collection
of recorded measurements on the computer and reviewing them for
obvious errors or missing data. Where possible discrepancies were
corrected and missing values reconstructed. A computer graphics
plot of this data was then compared to the back-up stripchart. If
plots were dissimilar, data were reevaluated and corrected, or
omitted and considered as missing data. Data quality was then
appropriately flagged. When a calendar month was completed, the
instrument calibration correction was applied and hourly, daily, and
monthly summaries were tabulated.

---

[1]Programs used in editing process were developed by G.
Venegopal and written in Apple BASIC.

DISCUSSION

A useful solar energy climatology must meet the basic demands of users of solar radiation information. To do this, it should contain statistics which accurately describe the central tendency (average) and the variability of radiation within the area of interest. It should also use a time interval where the statistic can be meaningful. For example, a yearly average is useless for determining the efficiency of a solar collector during the winter season. Both of these items have been considered in this study. For determining the best daily average statistic, mean versus median was compared. The average was then used as a variable in a time interval comparison of weekly versus monthly periods. Maps were then produced plotting the solar energy distribution of Utah (Figures 34 through 45).

Before proceeding any further, it should be noted that the data set contained many days of missing values. The lack of completeness of records is a factor that must be considered when interpreting the data. Every station record contains missing data. The percent of completeness ranges from a low of 15.7 percent (February; Lucin, Utah) to a high of 99.2 percent (October; Salt Lake City, Utah). Table 2 lists the completeness of records for each station by month. The degree of accuracy of the statistics produced in this study will vary considerably from station to station and should be used with caution.

Table 2. Quantity and completeness of station records

Month	Number of Daily Values in Data Set	Completeness of Record in Percent	Month	Number of Daily Values in Data Set	Completeness of Record in Percent
		--Kemmerer/Fontenelle, WY--			
Jan	70	56.5	July	100	80.6
Feb	42	38.9	Aug	101	81.5
Mar	60	48.4	Sep	103	85.8
Apr	27	22.5	Oct	95	76.6
May	67	54.0	Nov	80	66.7
Jun	102	85.0	Dec	70	56.5
		--Grace, ID--			
Jan	59	47.6	July	123	99.2
Feb	51	47.2	Aug	120	96.8
Mar	57	46.0	Sep	118	98.3
Apr	66	55.0	Oct	96	77.4
May	85	68.5	Nov	78	65.0
June	102	85.0	Dec	59	47.6
		--Logan, UT--			
Jan	107	86.3	July	89	71.8
Feb	99	91.7	Aug	111	89.5
Mar	120	96.8	Sep	114	95.0
Apr	112	93.3	Oct	121	97.6
May	118	95.2	Nov	98	81.7
June	101	84.2	Dec	89	71.8
		--Salt Lake City, UT--			
Jan	122	98.3	July	122	98.4
Feb	99	91.7	Aug	104	83.9
Mar	102	82.3	Sept	87	72.5
Apr	95	79.2	Oct	123	99.2
May	119	96.0	Nov	118	98.3
June	97	80.8	Dec	108	87.1

Table 2. Continued

Month	Number of Daily Values in Data Set	Completeness of Record in Percent	Month	Number of Daily Values in Data Set	Completeness of Record in Percent
--Lucin, UT*--					
Jan	71	57.3	July	79	63.7
Feb	17	15.7	Aug	77	62.1
Mar	53	42.7	Sep	75	62.5
Apr	67	55.8	Oct	72	58.1
May	56	45.2	Nov	53	44.2
June	67	55.8	Dec	57	46.0
--Altamont, UT*--					
Jan	30	24.2	Jul	48	38.7
Feb	36	33.3	Aug	50	48.3
Mar	51	41.1	Sep	57	47.5
Apr	53	44.2	Oct	53	42.7
May	48	38.7	Nov	34	28.3
Jun	52	43.3	Dec	25	20.2
--Delta, UT--					
Jan	115	92.7	Jul	91	73.4
Feb	75	69.4	Aug	85	68.5
Mar	88	71.0	Sep	60	50.0
Apr	116	96.7	Oct	50	40.3
May	95	76.6	Nov	56	46.7
Jun	86	71.7	Dec	51	41.1
--Ferron, UT--					
Jan	84	67.7	Jul	102	82.3
Feb	77	71.3	Aug	77	62.1
Mar	115	92.7	Sept	73	60.8
Apr	114	95.0	Oct	37	29.8
May	83	66.9	Nov	48	40.0
Jun	102	85.0	Dec	56	45.2

*Does not contain a four-year record

Table 2. Continued

Month	Number of Daily Values in Data Set	Completeness of Record in Percent	Month	Number of Daily Values in Data Set	Completeness of Record in Percent
--Cedar City, UT--					
Jan	113	91.1	Jul	100	80.6
Feb	98	90.7	Aug	110	88.7
Mar	118	95.2	Sep	111	92.5
Apr	113	94.2	Oct	123	99.2
May	119	96.0	Nov	98	81.7
Jun	117	97.5	Dec	103	83.1
--St. George, UT--					
Jan	80	64.5	Jul	76	61.3
Feb	102	94.4	Aug	64	51.6
Mar	92	74.2	Sep	75	62.5
Apr	109	90.8	Oct	77	62.1
May	92	74.2	Nov	105	87.5
Jun.	74	61.7	Dec	103	83.1

The distribution of global solar irradiance has been crudely shown for Utah in an atlas of national solar maps (SERI, 1981). This atlas is the only published reference resource available for individuals and businesses engaged in designing, installing and/or marketing solar energy conversion systems. Figure 2 shows a sample of the maps contained in the atlas.

Two problems have been found with using this atlas. The first is that the maps are drawn illustrating only the large national distribution of irradiance. Small grid variances are not depicted. It is an inadequate reference for accurately assessing the solar energy potentials for many geographic regions. This is particularly so in mountainous areas (Dirmhirm, 1985). The other concern is the statistic used to illustrate the spatial distributions of radiant energy on the maps. Plots of a station's arithmetic mean are contoured. Although this value is needed to determine the total insolation for a given period, it has been demonstrated that it is not the best statistic for representing the 50 percent probability level of insolation data. Users of the atlas are either unaware or are intentionally ignoring the fact that they will be making errors in determining the solar energy potential for geographic locations. One goal of this effort is to remedy this situation for the State of Utah.

Expressing Central Tendency and Variability

The starting point for analyzing the Utah Solar Network data was deciding which statistic best described the average and
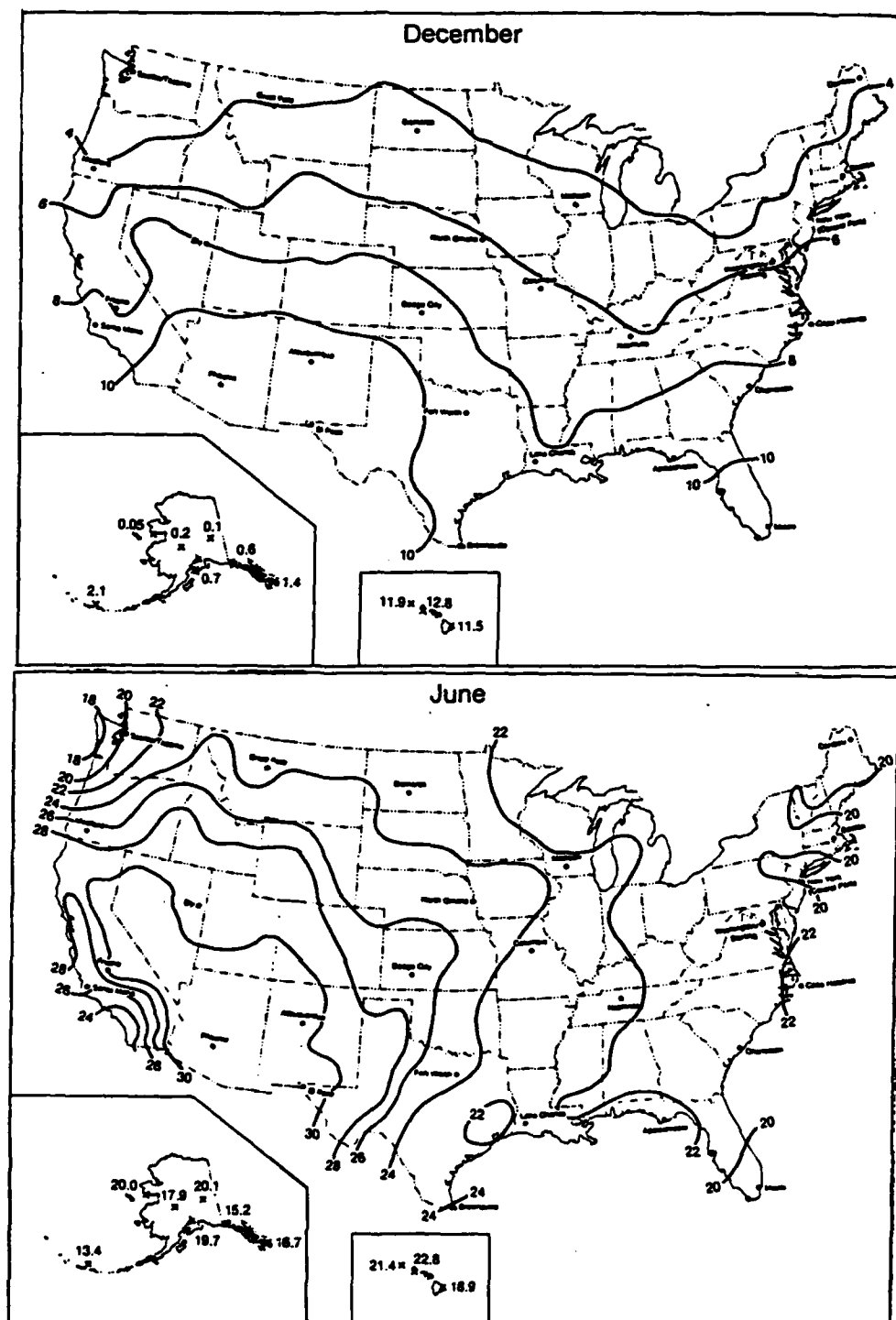
Figure 2. The distribution of global solar irradiance in the United States during December and June. (SERI, 1981) (units are MJ m^{-2} day^{-1})

variability of radiant energy in the state. Two measures of an average were calculated. The sample mean using this formula:

$$X = \frac{\sum_{i=1}^{n} X_i}{n}$$

and the median using these formulas:

$$\tilde{X} = X_{n+1/2} \qquad \text{if n is odd}$$

$$\tilde{X} = \frac{X_{n/2} + X_{(n/2)+1}}{2} \qquad \text{if n is even}$$

$X_1, X_2, \ldots X_n$ are arranged in increasing order of magnitude

A comparison of the sample means and medians were performed by subtracting the median from the mean. This calculation was performed on weekly and monthly data groupings for each station. Graphs have been produced showing the results (see Figures 3 through 12).

A large difference, either positive or negative indicates that there is a non-symmetrical distribution of data values. This results in a skewed frequency distribution curve (Figures 13a and 13b). If the mean is used as the average for these distributions it will incorrectly represent the 50 percent probability level. The median should be used instead because it more effectively separates the data in two equal parts (50 percent of the values are higher and 50 percent are lower).

Figure 3. The difference between mean and median daily radiation for each week and month of the year.

Cedar City
Global Mean–Median

Cedar City
Global Mean–Median
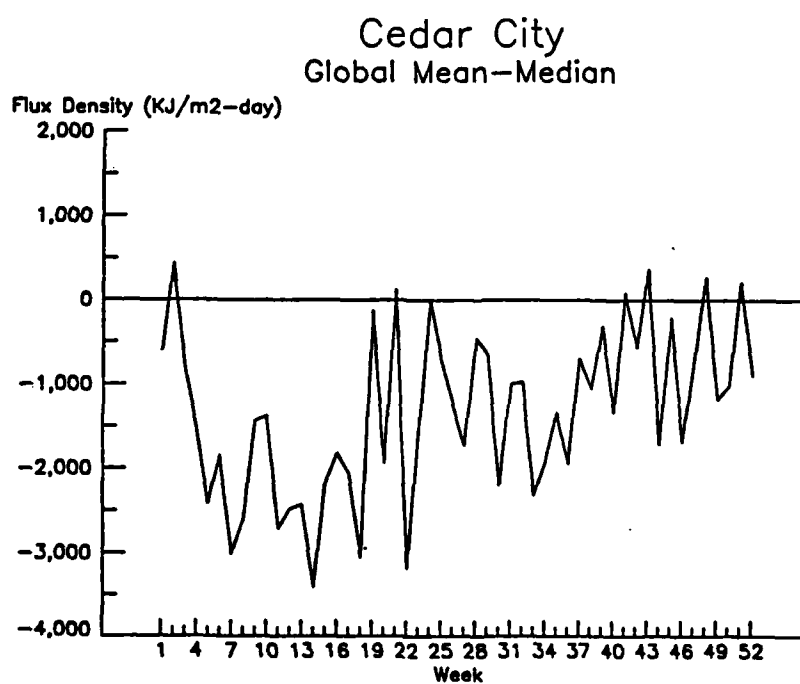
Figure 4. The difference between mean and median daily radiation
for each week and month of the year.

Figure 5. The difference between mean and median daily radiation
for each week and month of the year.

Ferron
Global Mean—Median

Ferron
Global Mean—Median

Figure 6. The difference between mean and median daily radiation
for each week and month of the year.

Grace
Global Mean—Median

Flux Density (KJ/m2—day)

Grace
Global Mean—Median

Flux Density (KJ/m2—day)

Figure 7. The difference between mean and median daily radiation
for each week and month of the year.

Kennerer/Fontenelle
Global Mean—Median

Flux Density (KJ/m2—day)

Kemmerer/Fontenelle
Global Mean—Median

Flux Density (KJ/m2—day)
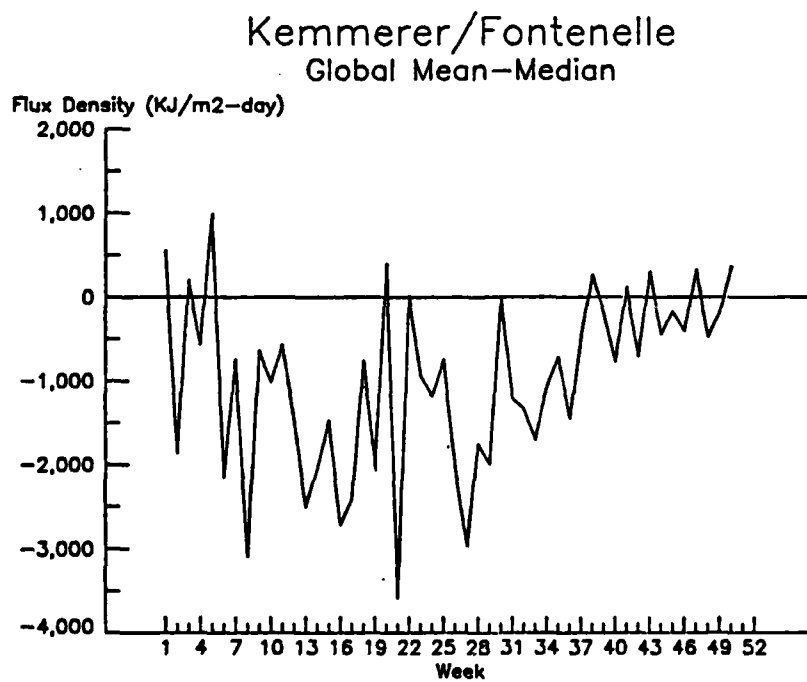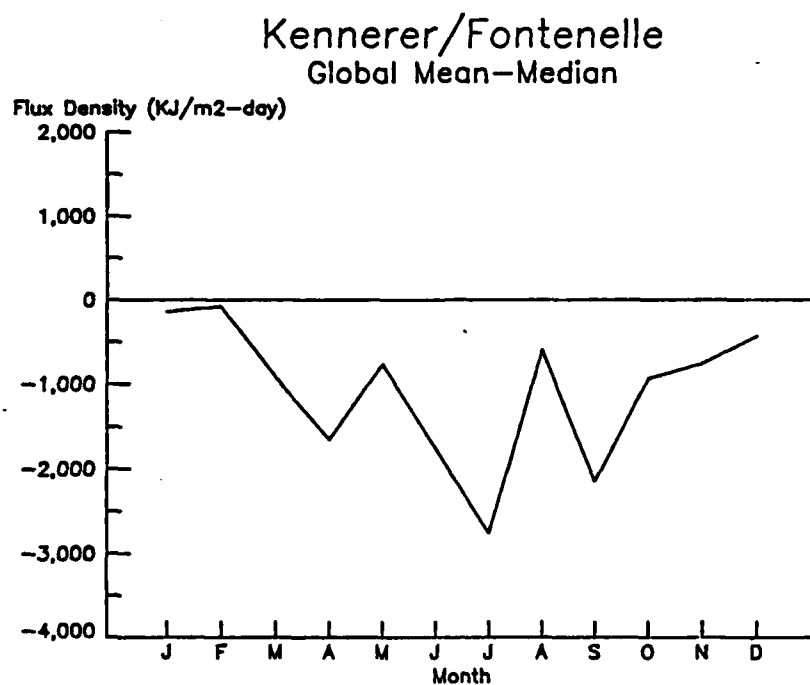
Figure 8.   The difference between mean and median daily radiation
for each week and month of the year.
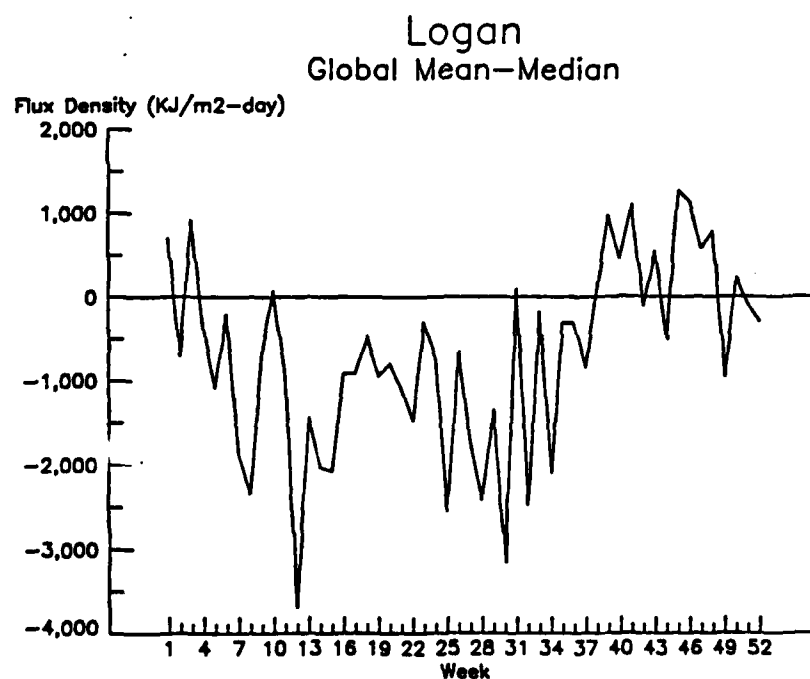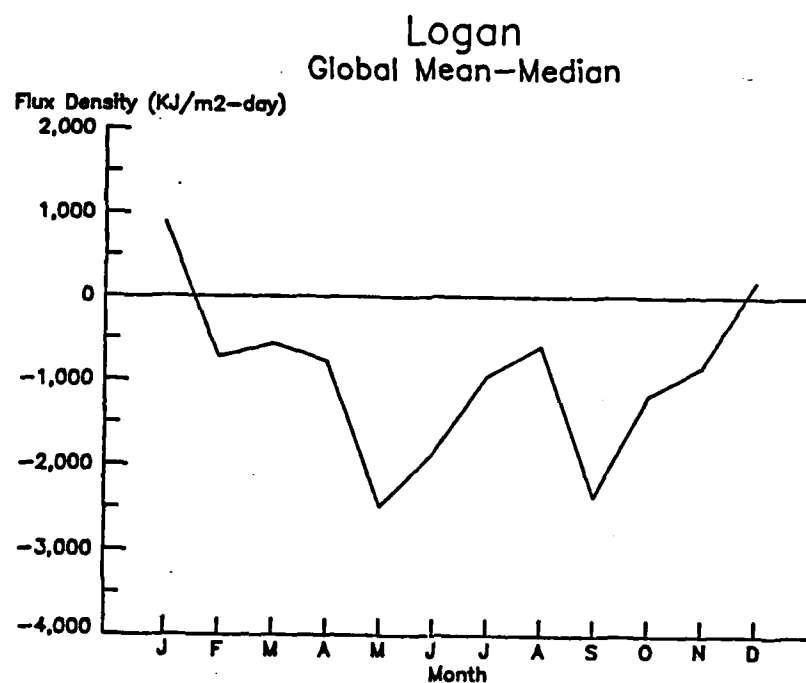
Figure 9. The difference between mean and median daily radiation for each week and month of the year.
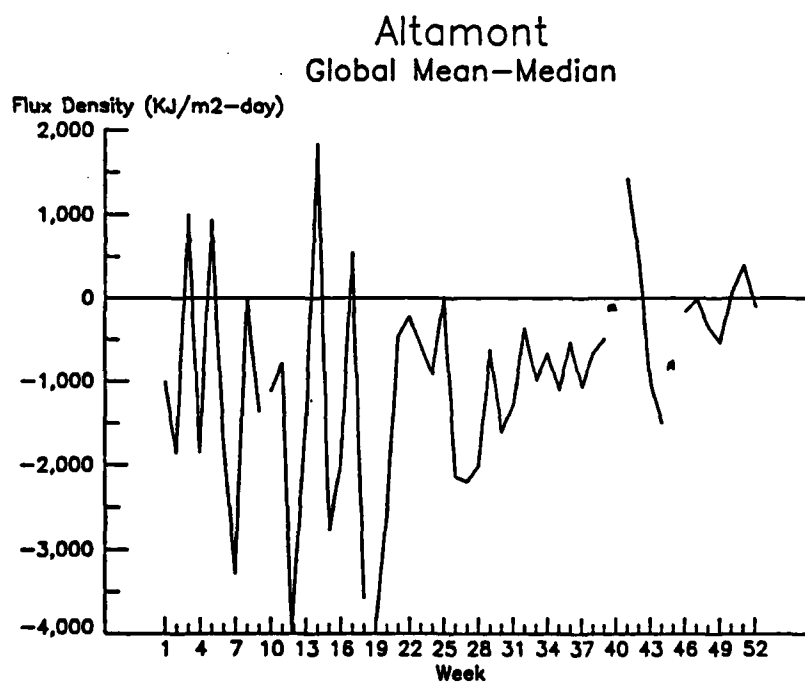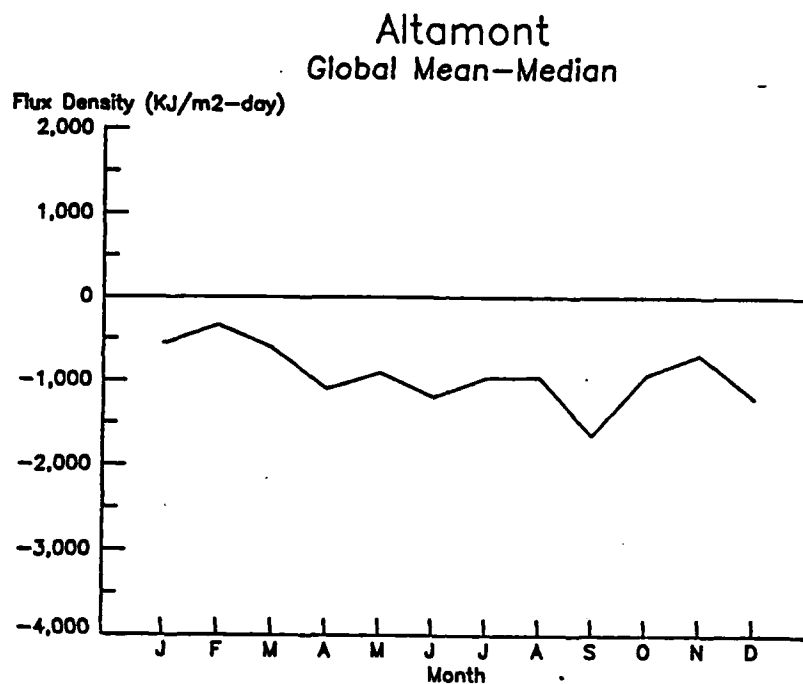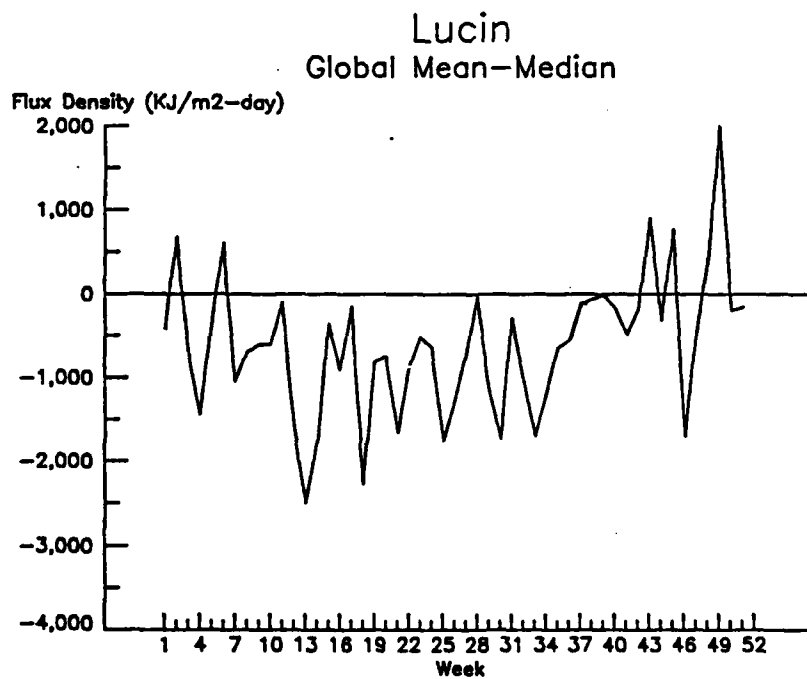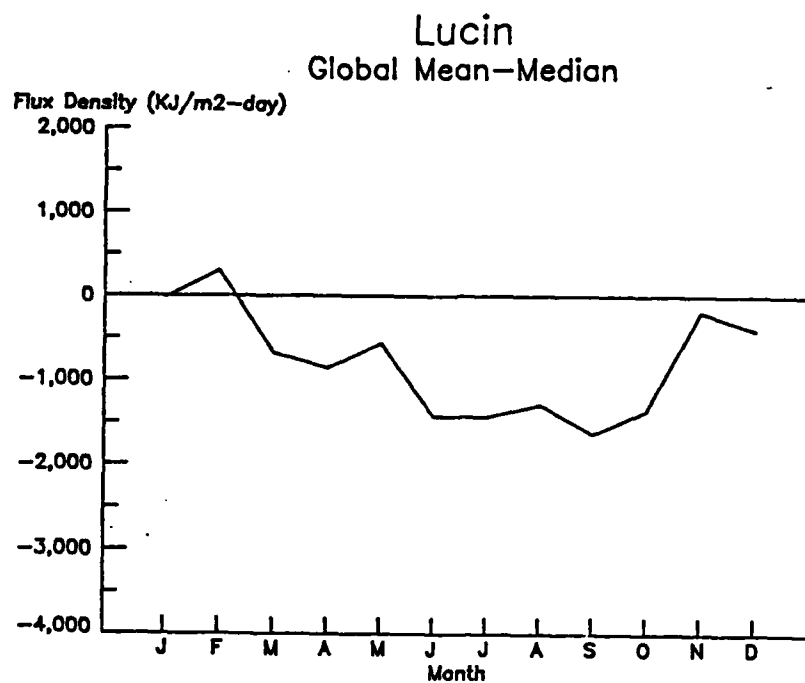
Figure 10. The difference between mean and median daily radiation for each week and month of the year.

Salt Lake City
Global Mean—Median

Salt Lake City
Global Mean—Median
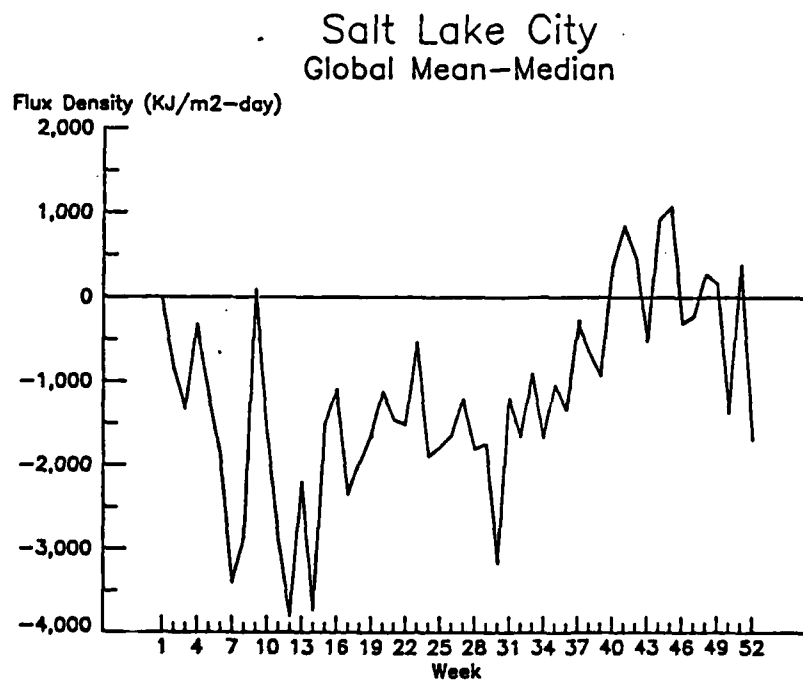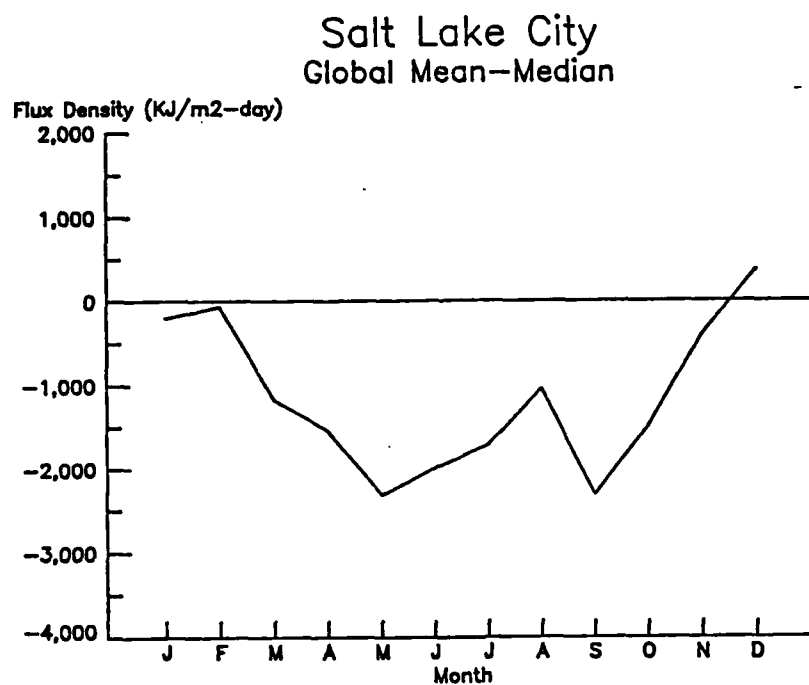
Figure 11. The difference between mean and median daily radiation for each week and month of the year.

St. George
Global Mean–Median

St. George
### Global Mean–Median
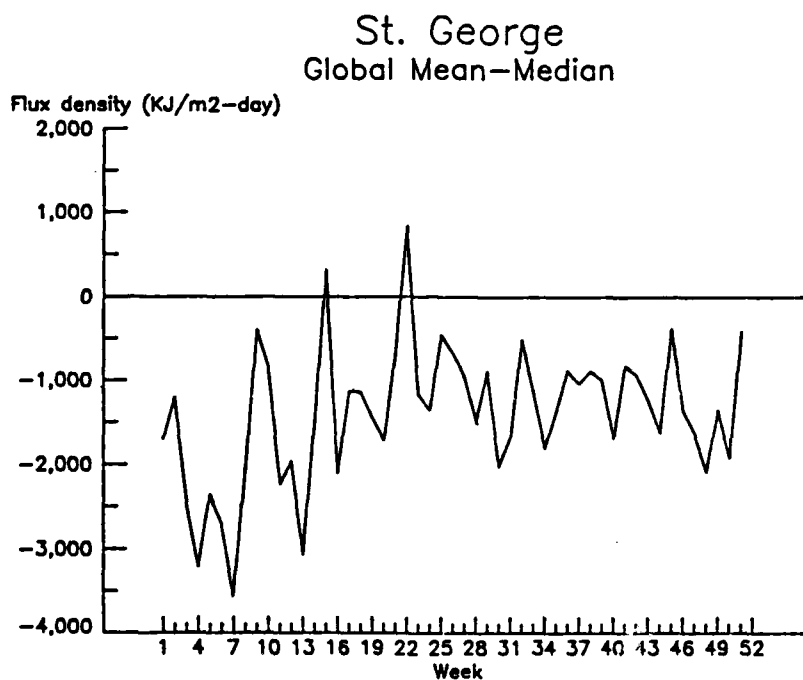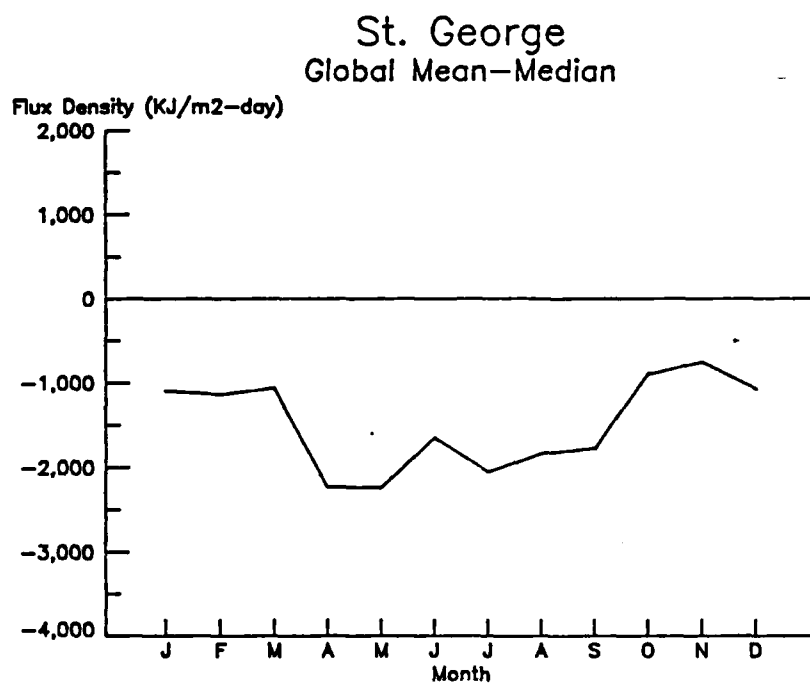
Figure 12.   The difference between mean and median daily radiation
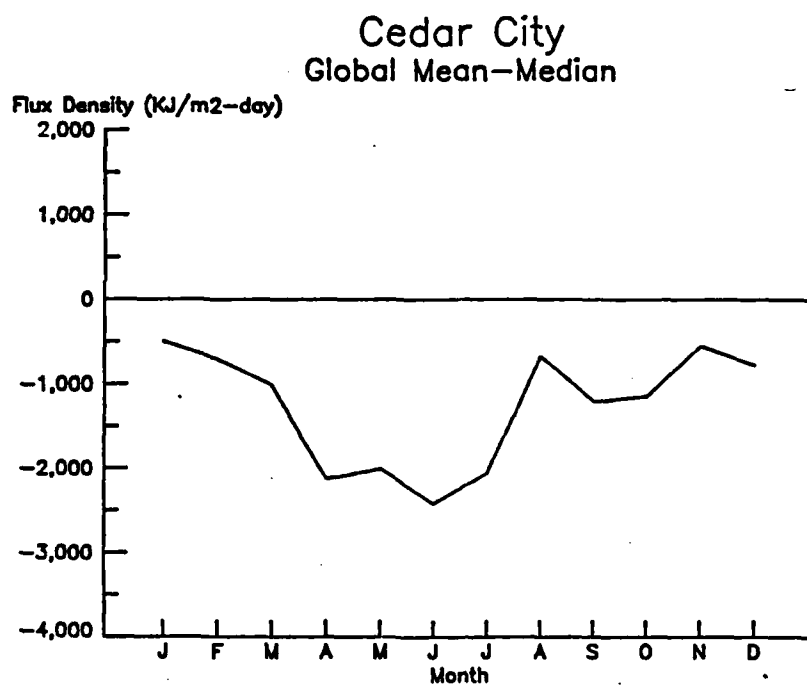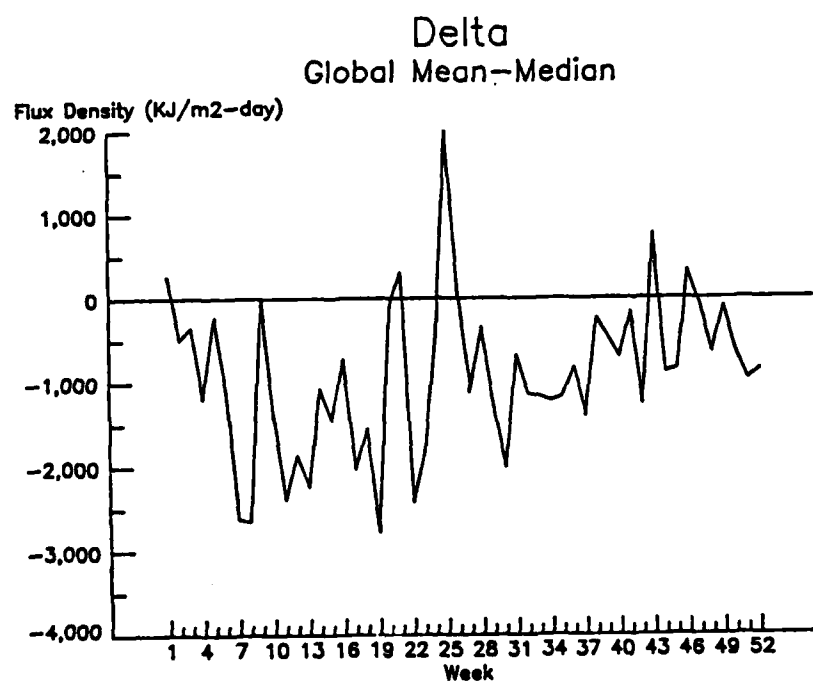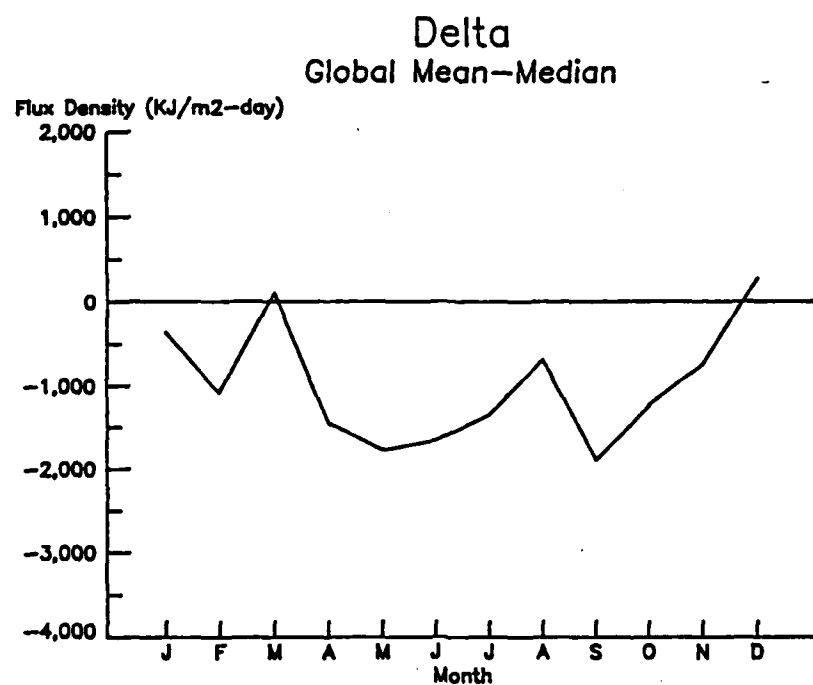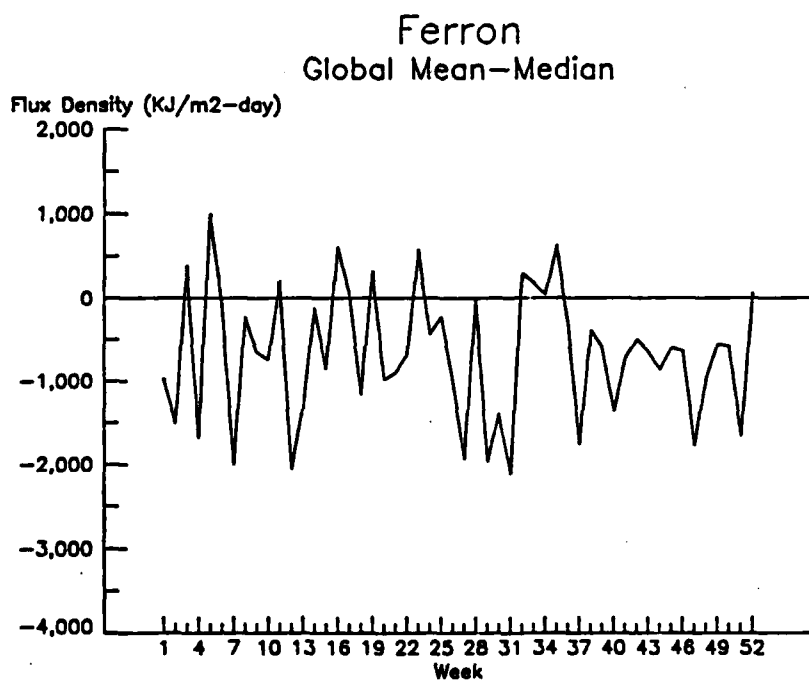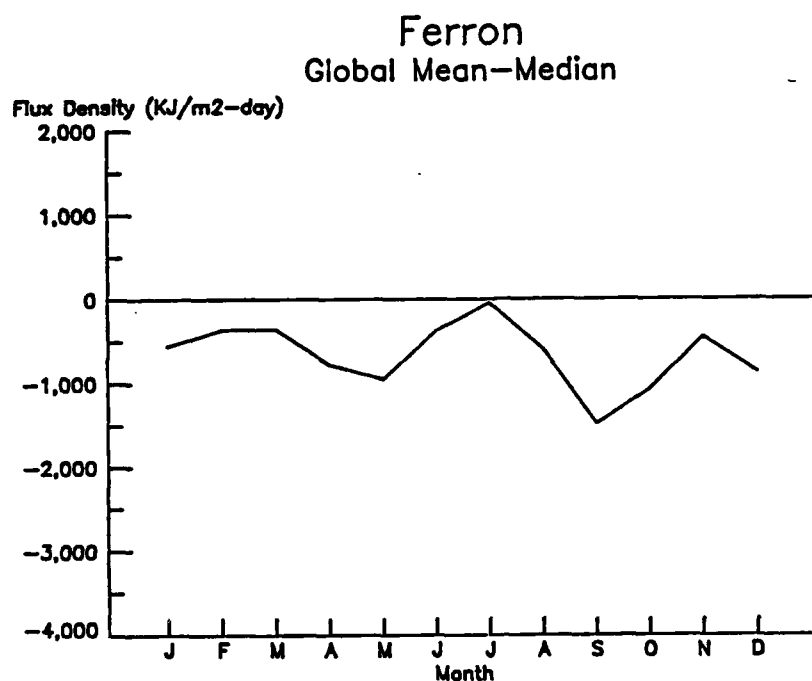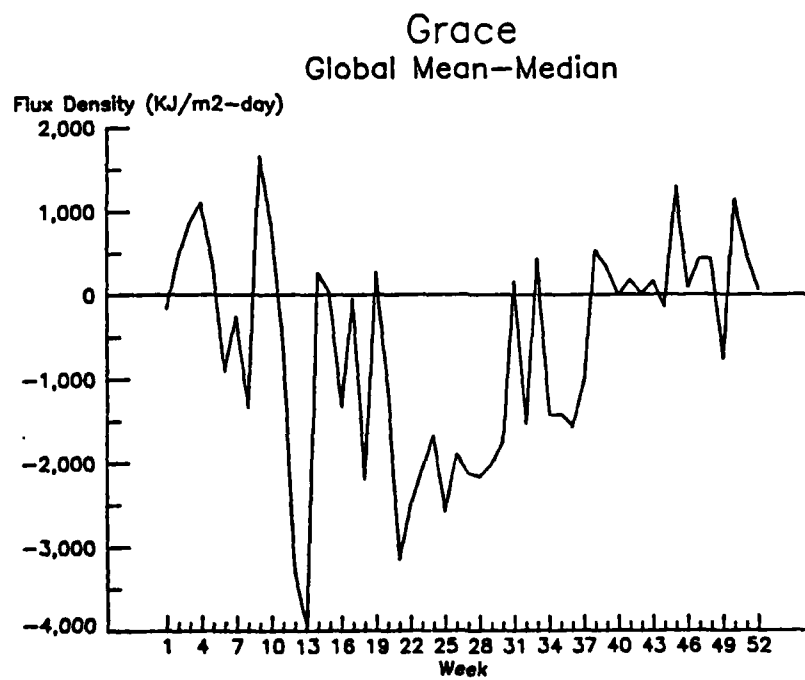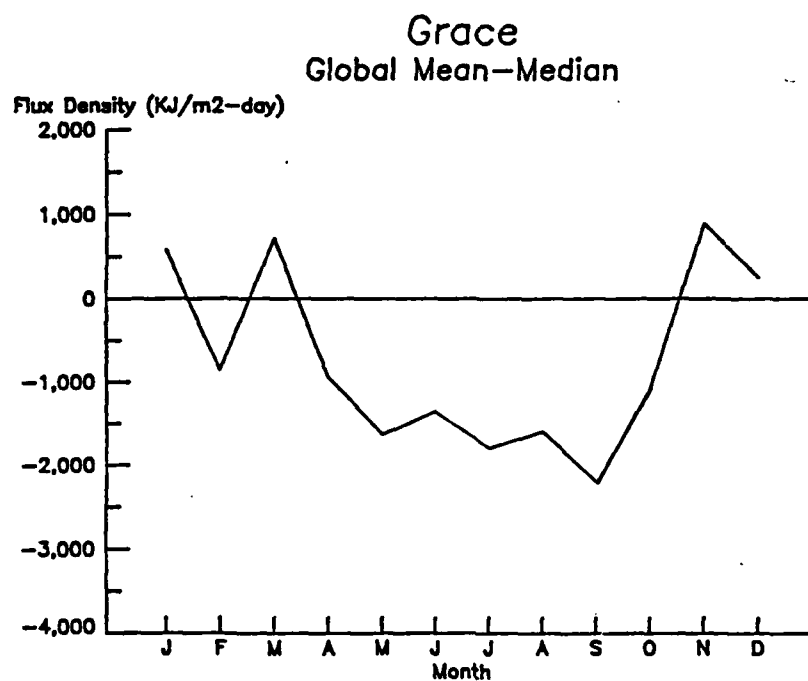for each week and month of the year.

(a)

CLASS LIMITS	FREQUENCY	
1000.00 < 2000.00	2	
2000.00 < 3000.00	18	
3000.00 < 4000.00	17	
4000.00 < 5000.00	20	
5000.00 < 6000.00	9	
6000.00 < 7000.00	4	
7000.00 < 8000.00	11	
8000.00 < 9000.00	9	
9000.00 < 10000.00	9	
10000.00 < 11000.00	4	
11000.00 < 12000.00	4	

Logan
January

(b)

CLASS LIMITS	FREQUENCY	
8000.00 < 10000.00	1	
10000.00 < 12000.00	2	
12000.00 < 14000.00	2	
14000.00 < 16000.00	2	
16000.00 < 18000.00	3	
18000.00 < 20000.00	2	
20000.00 < 22000.00	1	
22000.00 < 24000.00	6	
24000.00 < 26000.00	4	
26000.00 < 28000.00	9	
28000.00 < 30000.00	10	
30000.00 < 32000.00	35	
32000.00 < 34000.00	35	
34000.00 < 36000.00	5	

Cedar City
June

(c)

CLASS LIMITS	FREQUENCY	
2000.00 < 3000.00	3	
3000.00 < 4000.00	0	
4000.00 < 5000.00	3	
5000.00 < 6000.00	3	
6000.00 < 7000.00	5	
7000.00 < 8000.00	13	
8000.00 < 9000.00	8	
9000.00 < 10000.00	5	
10000.00 < 11000.00	8	
11000.00 < 12000.00	8	
12000.00 < 13000.00	7	
13000.00 < 14000.00	12	
14000.00 < 15000.00	6	
15000.00 < 16000.00	10	
16000.00 < 17000.00	6	
17000.00 < 18000.00	2	

Salt Lake City
February

Figure 13.   Frequency distribution curves (a) positive skewed
curve, (b) negative skewed curve, and (c) bimodal
curve.

Differences close to zero were first thought to coincide with a "normal" distribution, but after plotting several of the distributions, this proved not to be true. Instead, most of these cases showed a bimodal distribution pattern (Figure 13c). It can be noted, that this type of curve can use either the median or mean to predict the 50 percent probability level. After examining all the distribution curves, only a few actually displayed a "normal" curve.

The spring and summer months (the high sun period) for each station, in general, had large negative differences. These weeks and months had frequency distribution curves that were negatively skewed. This type of curve is indicative of predominantly clear or partly cloudy skies with only occasional days of mostly cloudy and/or overcast conditions. In contrast, in the late fall and during winter (the low sun period) there was a tendency to have differences that were positive. This of course, corresponded to a positively skewed frequency distribution curve. Curves of this shape, demonstrate that there was a high frequency of cloudy days and only a few days where sunshine was abundant. Bimodal frequency distributions happened as a result of some years being pre-dominantly cloudy and other years being predominantly clear for the respective evaluation period.

With most of the evaluation periods being skewed, the median should be used to represent the "average" daily radiant energy value, because it more realistically depicts the 50 percent probability level. From this point on, all references to the average will be the median value for the respective time period.
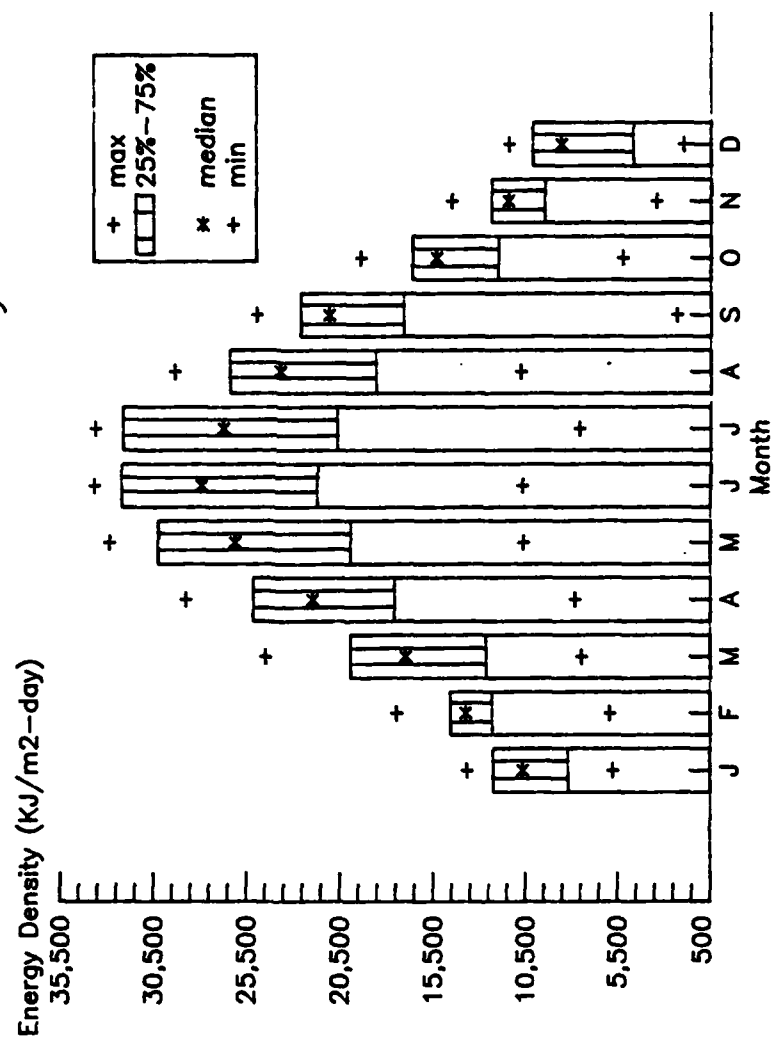
Figure 14.   Annual variation of daily totals of global irradiance by month.
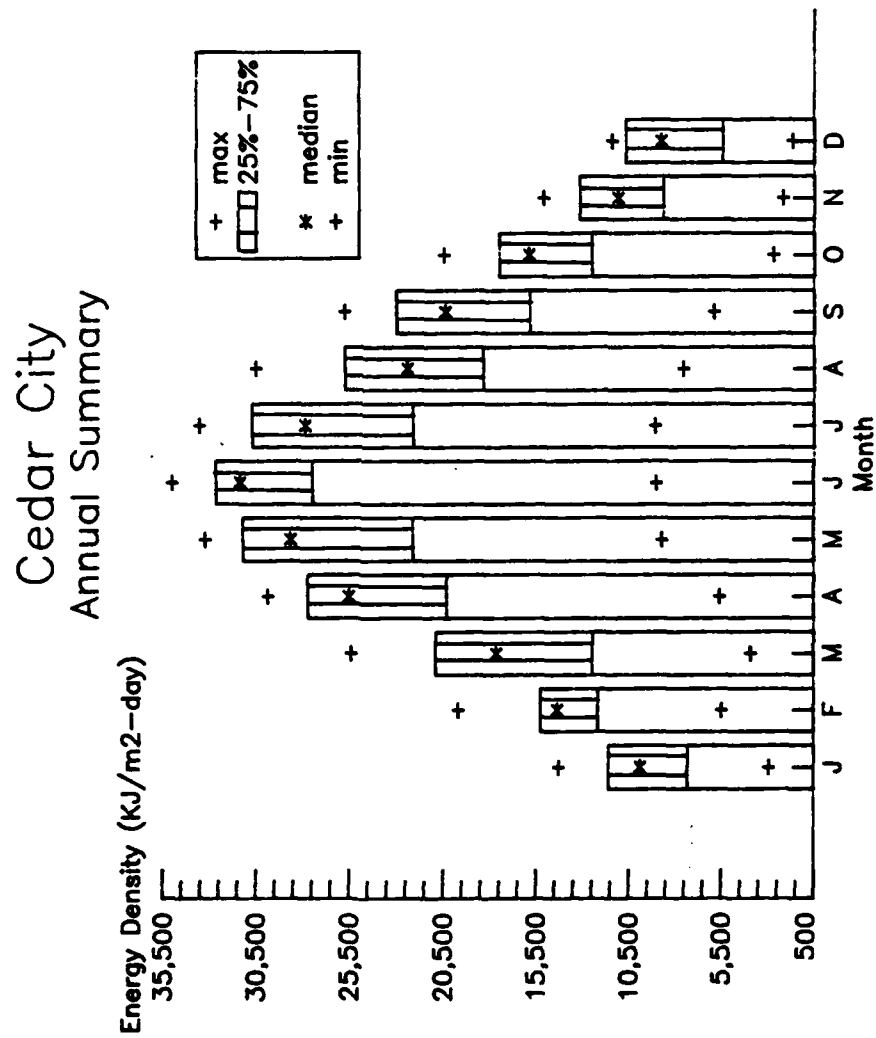
Figure 15. Annual variation of daily totals of global irradiance by month.
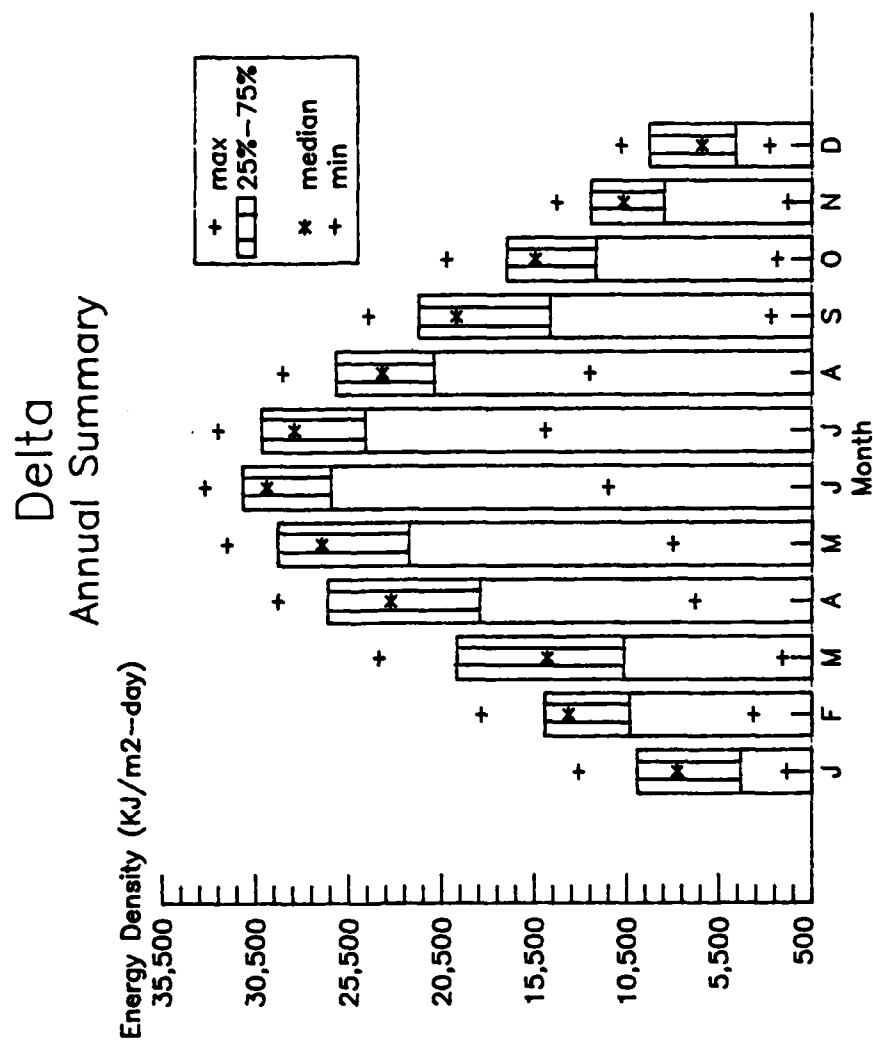
Figure 16.   Annual variation of daily totals of global irradiance by month.
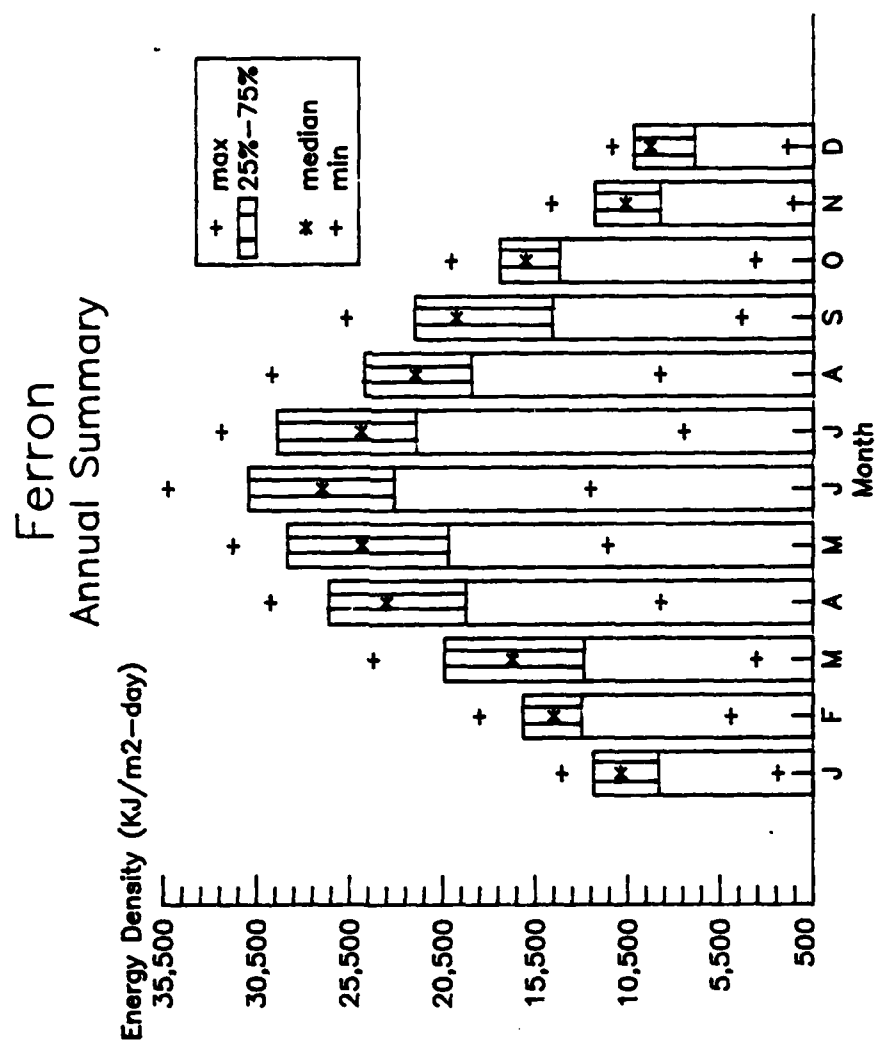
Figure 17. Annual variation of daily totals of global irradiance by month.
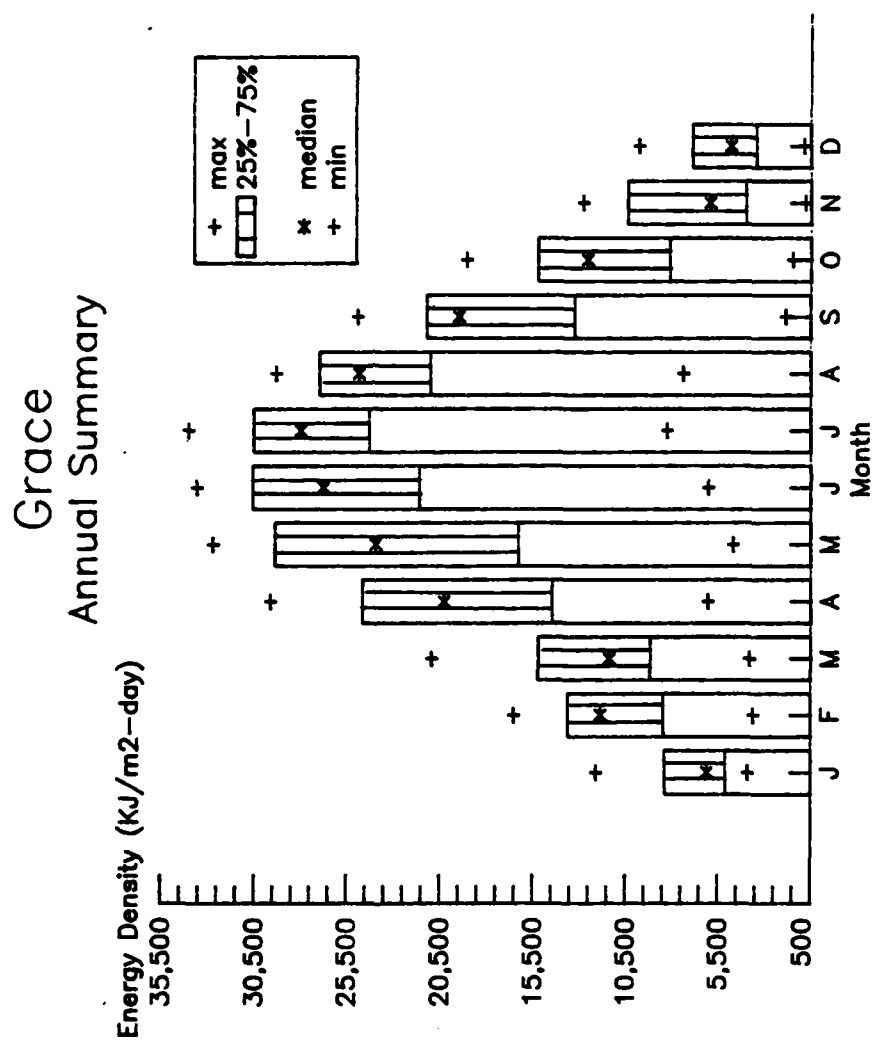
Figure 18. Annual variation of daily totals of global irradiance by month.
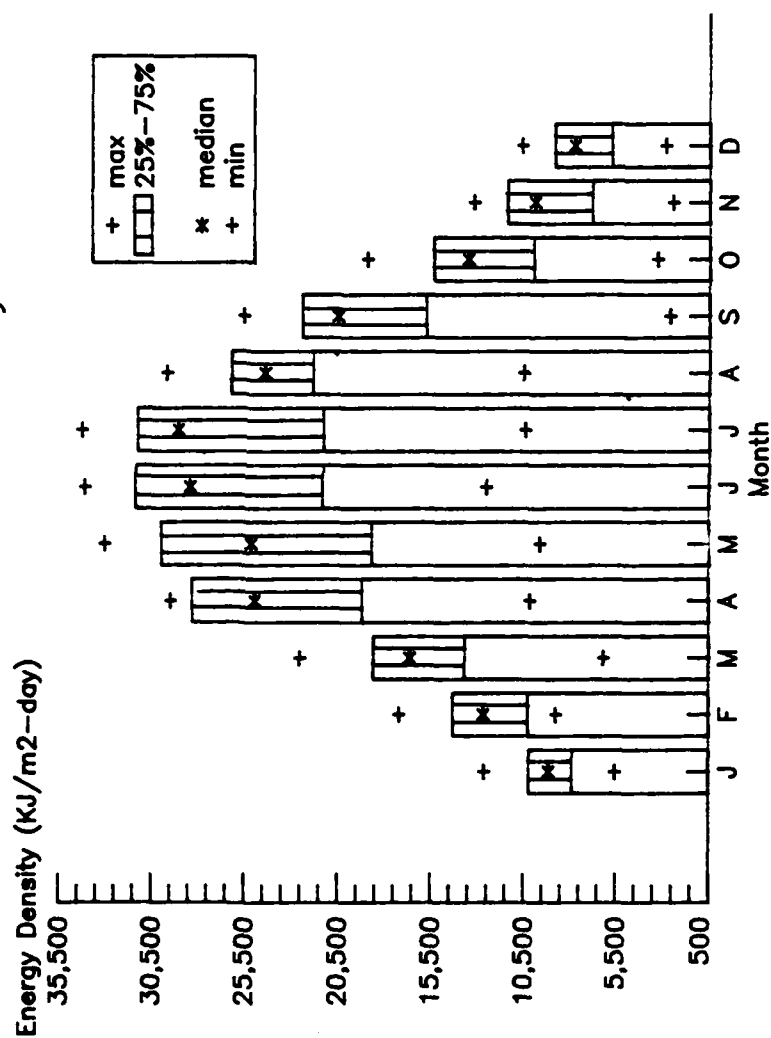
Figure 19. Annual variation of daily totals of global irradiance by month.
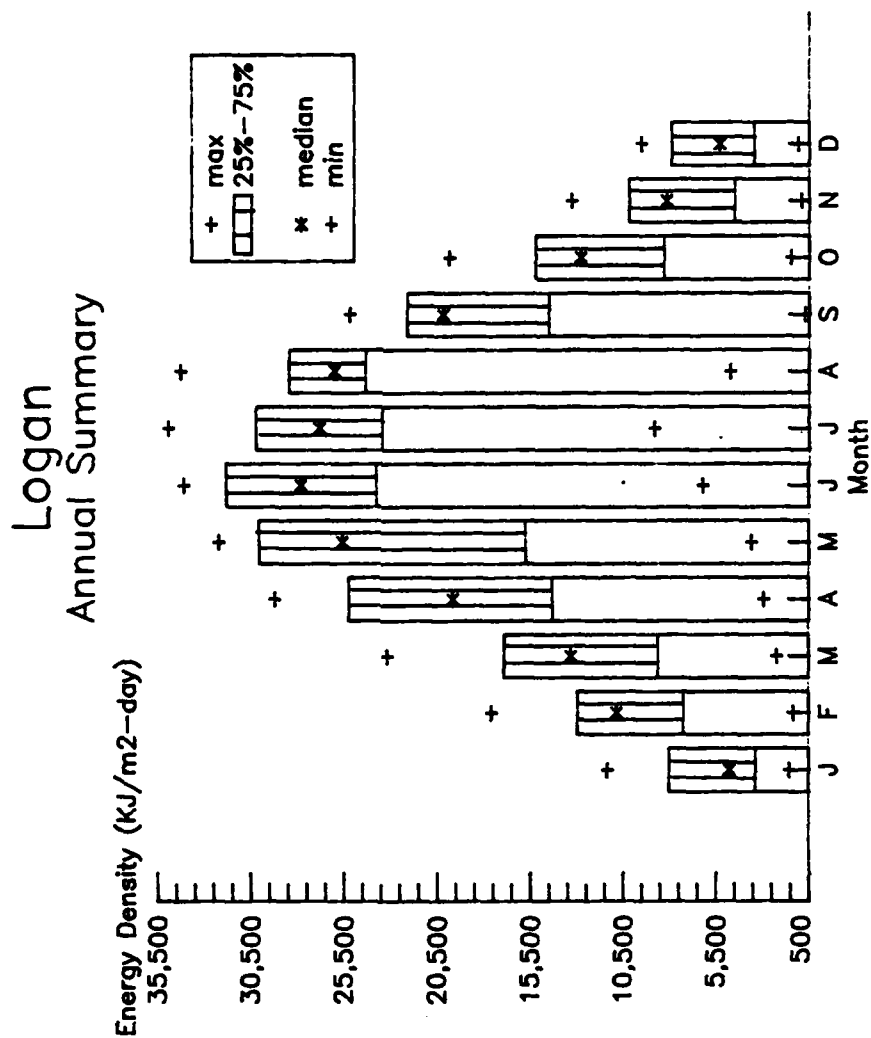
Figure 20. Annual variation of daily totals of global irradiance by month.
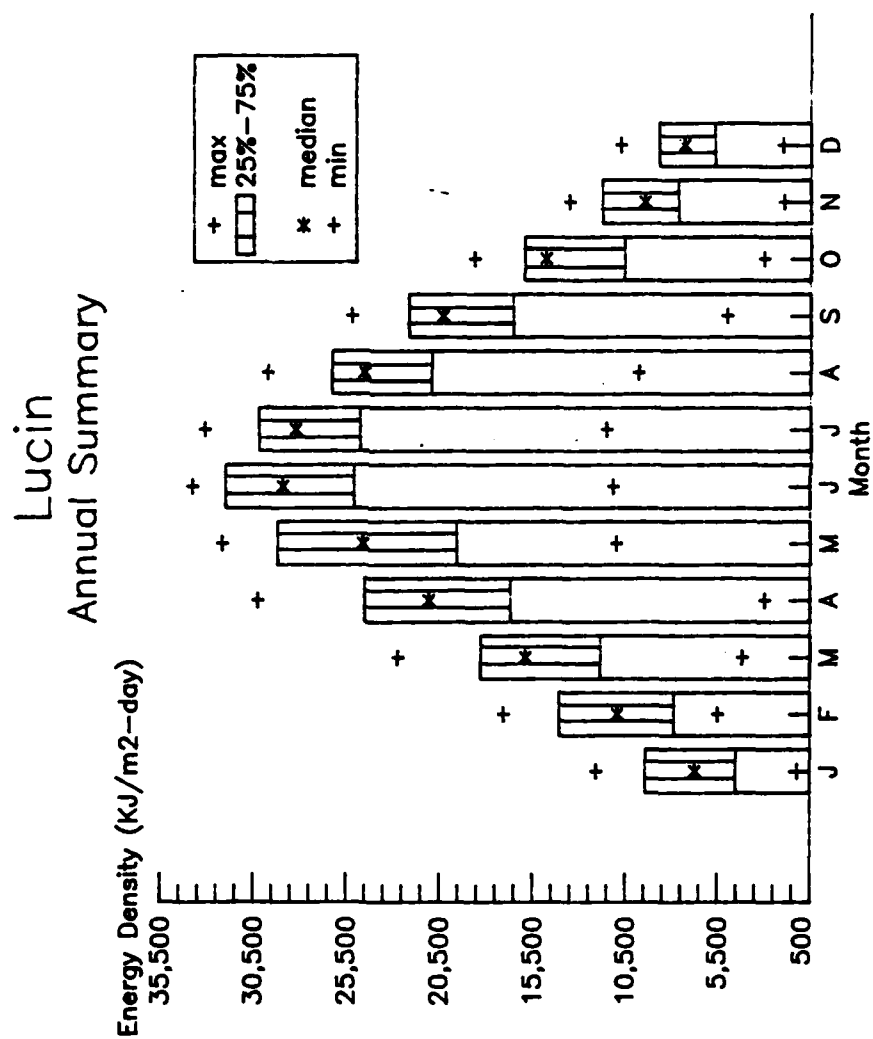
Figure 21. Annual variation of daily totals of global irradiance by month.
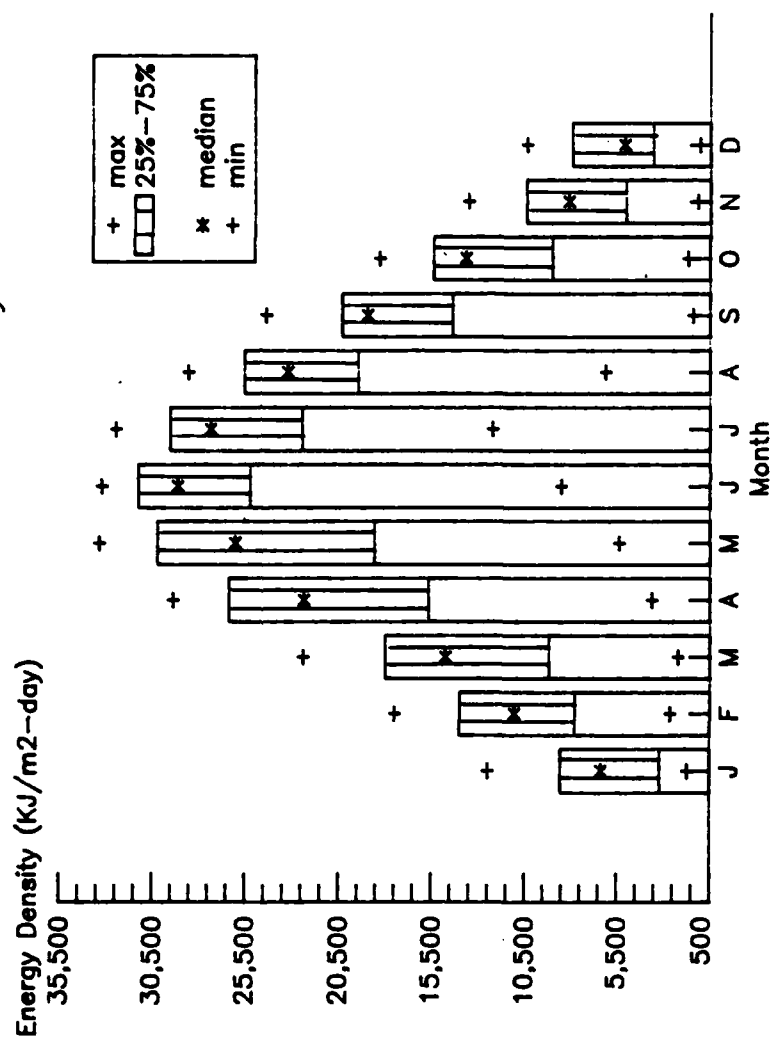
Figure 22.   Annual variation of daily totals of global irradiance by month.

St. George
Annual Summary
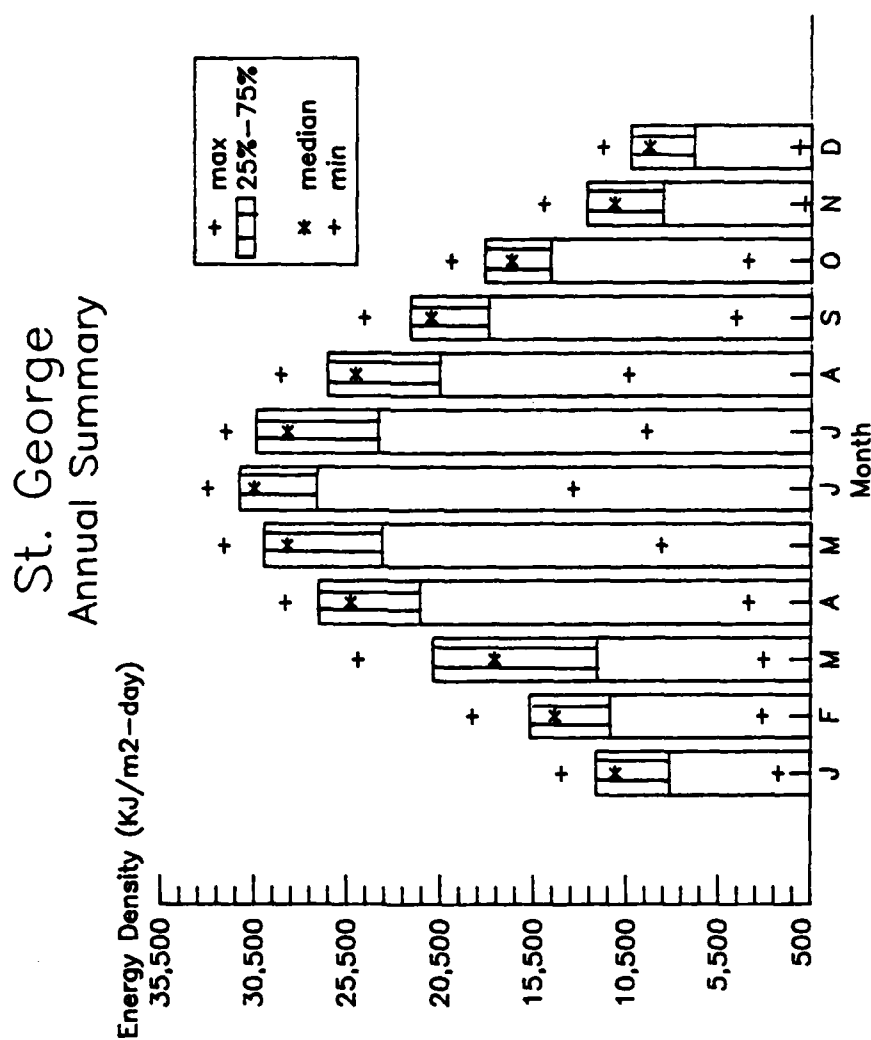
Figure 23. Annual variation of daily totals of global irradiance by month.

To show the variability of radiation data, the maximum, minimum 25th and 75th percentiles were calculated. These values including the median have all been plotted on one graph for each station. In Figures 14 through 23, the asterisk (*) represents the median or average value. The hatched area outlines the radiant energy range between the 25 and 75 percent probability levels and shows where 50 percent of the daily totals of irradiance occurs. The plus (+) signs above and below the hatched area are the maximum and minimum values, respectively. These calculated values are also available in tabular form (see Appendix).

Valuable information about the variability is contained in these graphs. Large ranges between the maximum and minimum are shown during every month of the year for each station. This indicates to users of solar energy that a back-up energy source will probably be necessary at several times of the year. Also, the large variance in time indicates that a large data base is necessary to determine accurate expected values and probability levels.

Time Period Considerations

The next step in describing Utah's solar energy climate is to present statistical information over a time unit that accurately details the seasonal variability of solar irradiance. This objective has often been overlooked, but should not be because it is just as important as choosing the appropriate statistical measurements. Often a time interval is selected that is too long, and valuable information is lost from the inherent smoothing process of obtaining an average. For this reason, statisical information was computed for monthly and weekly time periods.

Both time period averages were plotted on the same graph for a visual comparison (see Figures 24-33). The line graph depicts the daily average computed over week intervals and the bar graph indicates the daily average, computed over a month. The monthly values have been plotted against the week number which contains the mid-month date (15th day).

Examining the graphs, reveals that twice yearly, in the spring and in the fall, the weekly daily averages vary greatly from the monthly daily average. This demonstrates that the data are not self-similar with respect to time. Changes are occurring too abruptly for the monthly time interval average to capture them. Valuable information is being lost as the monthly average smoothes through the changes. This occurs because of two reasons: weather patterns are transitioning, causing beginning of the month weather and energy values to be quite different than at the end of the month. Also, the length of day is changing most rapidly during these seasons. For these reasons, the shorter time interval averages should be used to get a better estimate of the expected energy availability. It would be impractical to plot weekly maps so data will only be presented in tabular form (Appendix). Climatological weeks are used for the time units. Beginning and ending weeks for each grouping are: Week 1 is the week March 1-7, week 9 is the week April 26-May 2, week 28 is the week of September 6-12 and week 36 is the week of November 1-7.
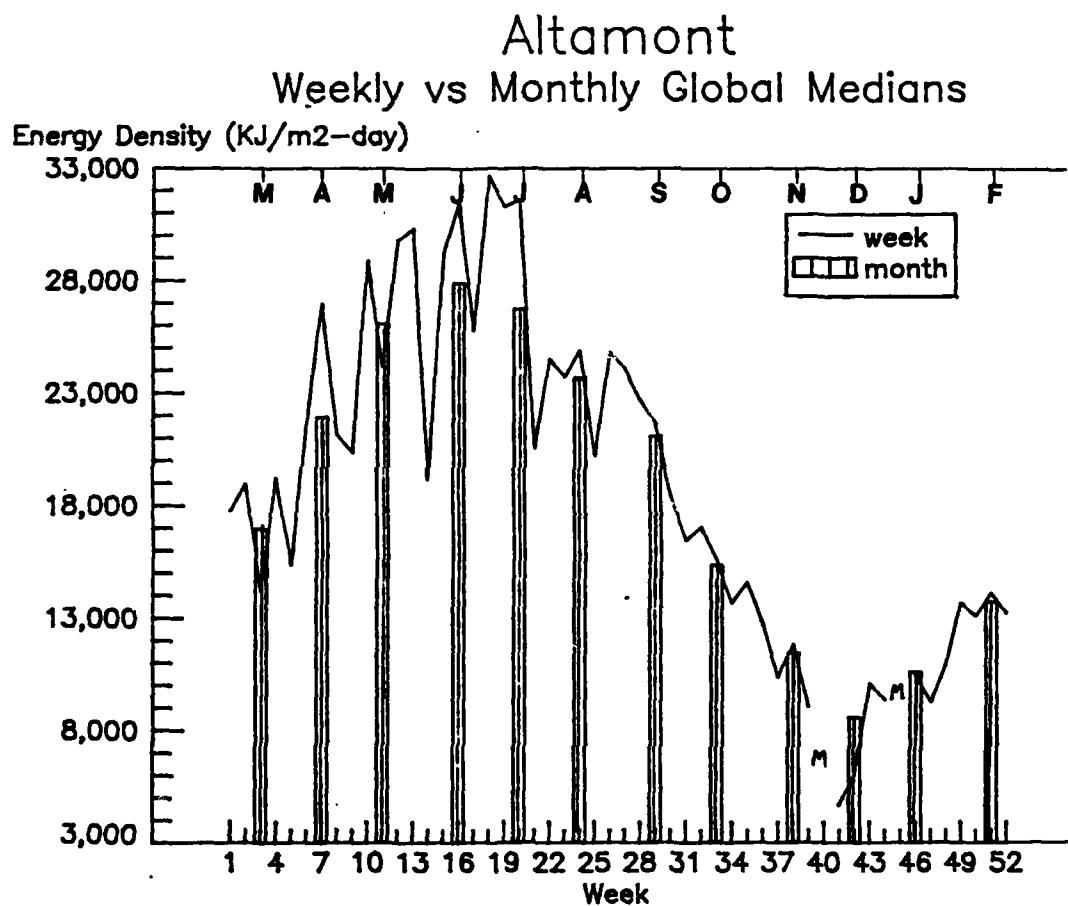
Figure 24. Comparison of weekly versus monthly daily averages.
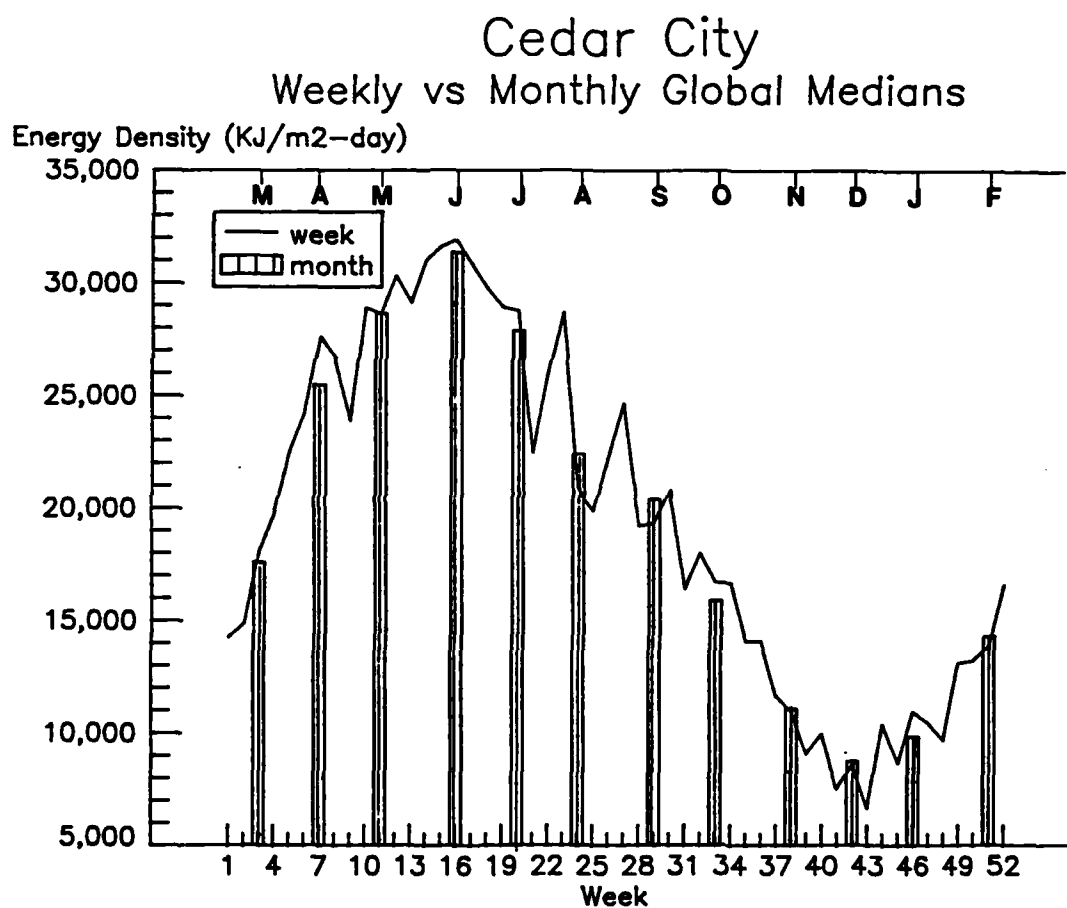
Figure 25. Comparison of weekly versus monthly daily averages.

Delta
Weekly vs Monthly Global Medians
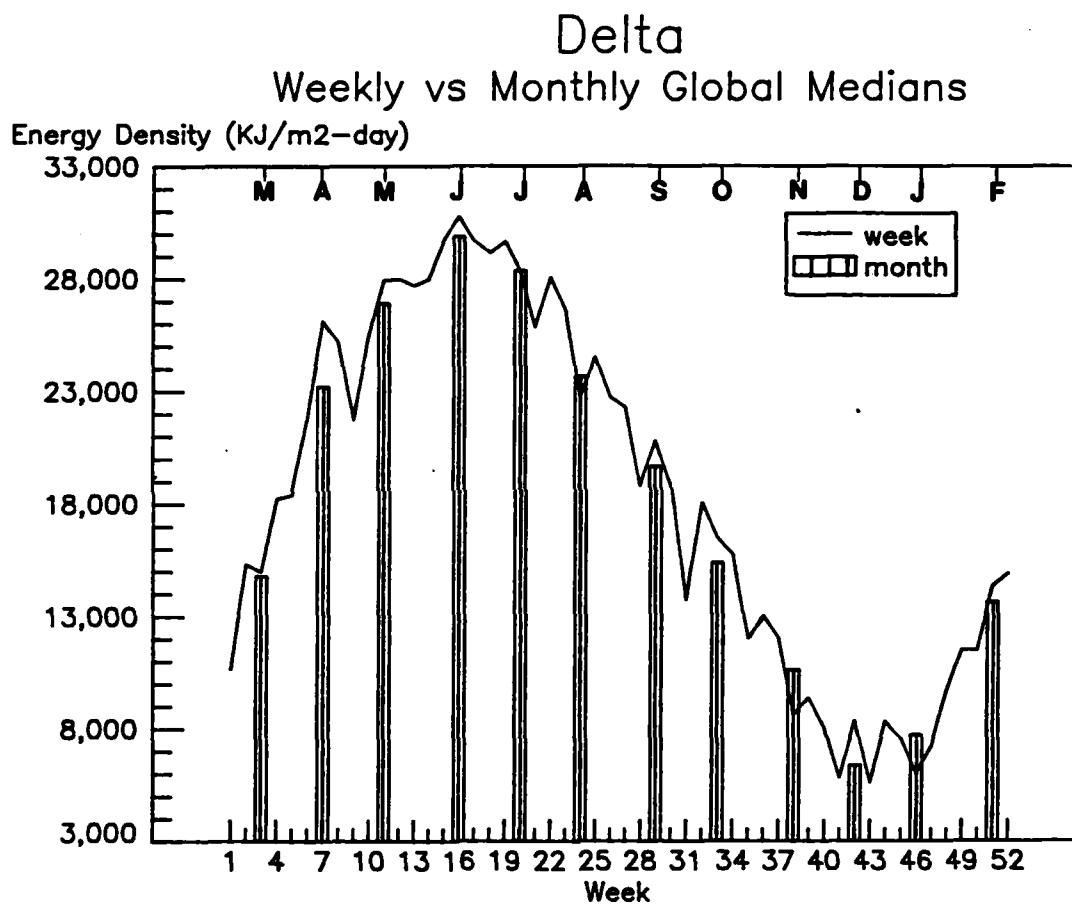
Figure 26. Comparison of weekly versus monthly daily averages.

Ferron
Weekly vs Monthly Global Medians
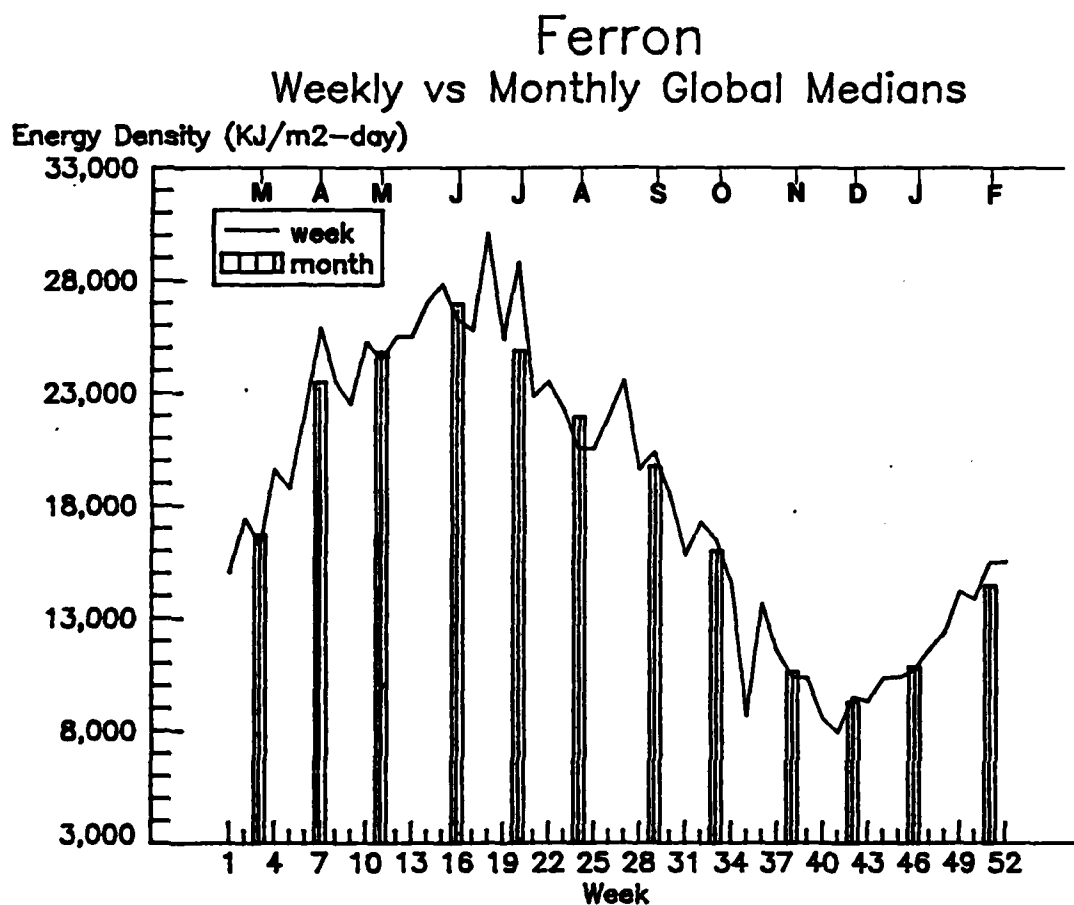
Figure 27. Comparison of weekly versus monthly daily averages.

Grace
Weekly vs Monthly Global Medians
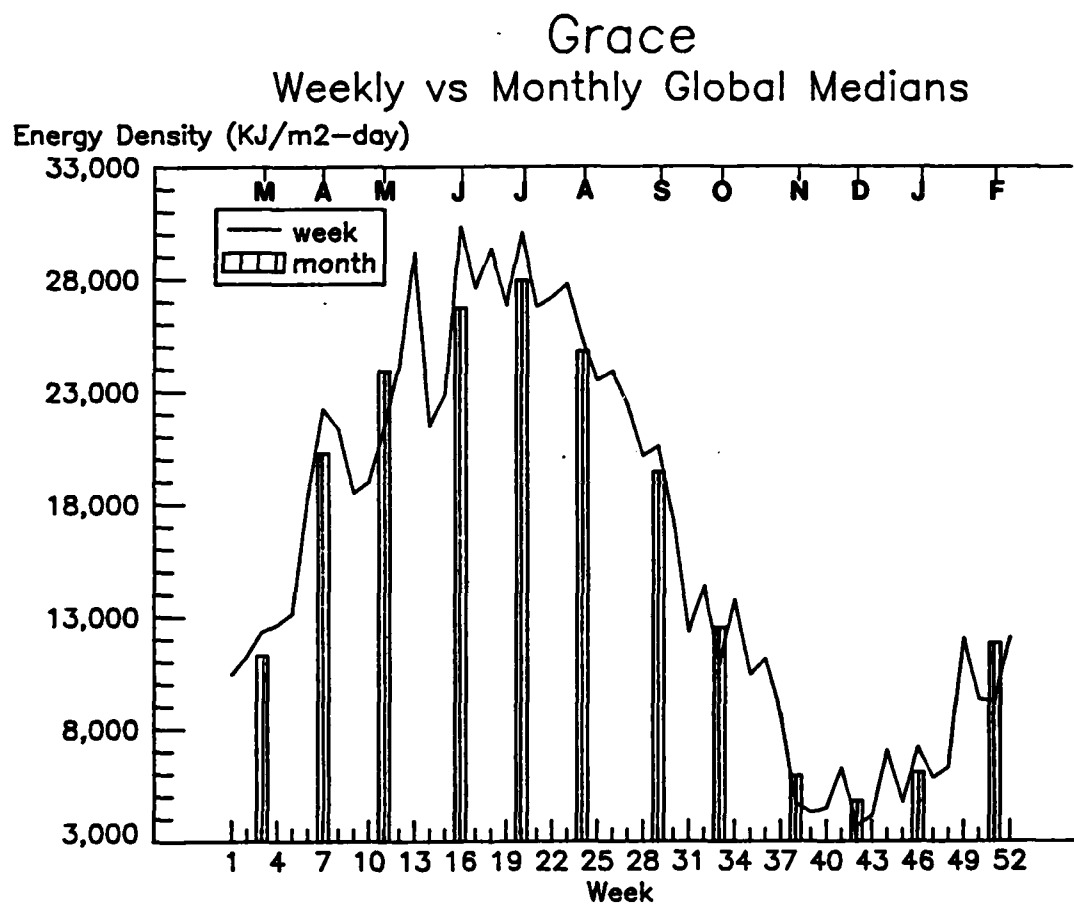
Figure 28. Comparison of weekly versus monthly daily averages.

Kemmerer/Fontenelle
Weekly vs Monthly Global Medians

Energy Density (KJ/m2–day)
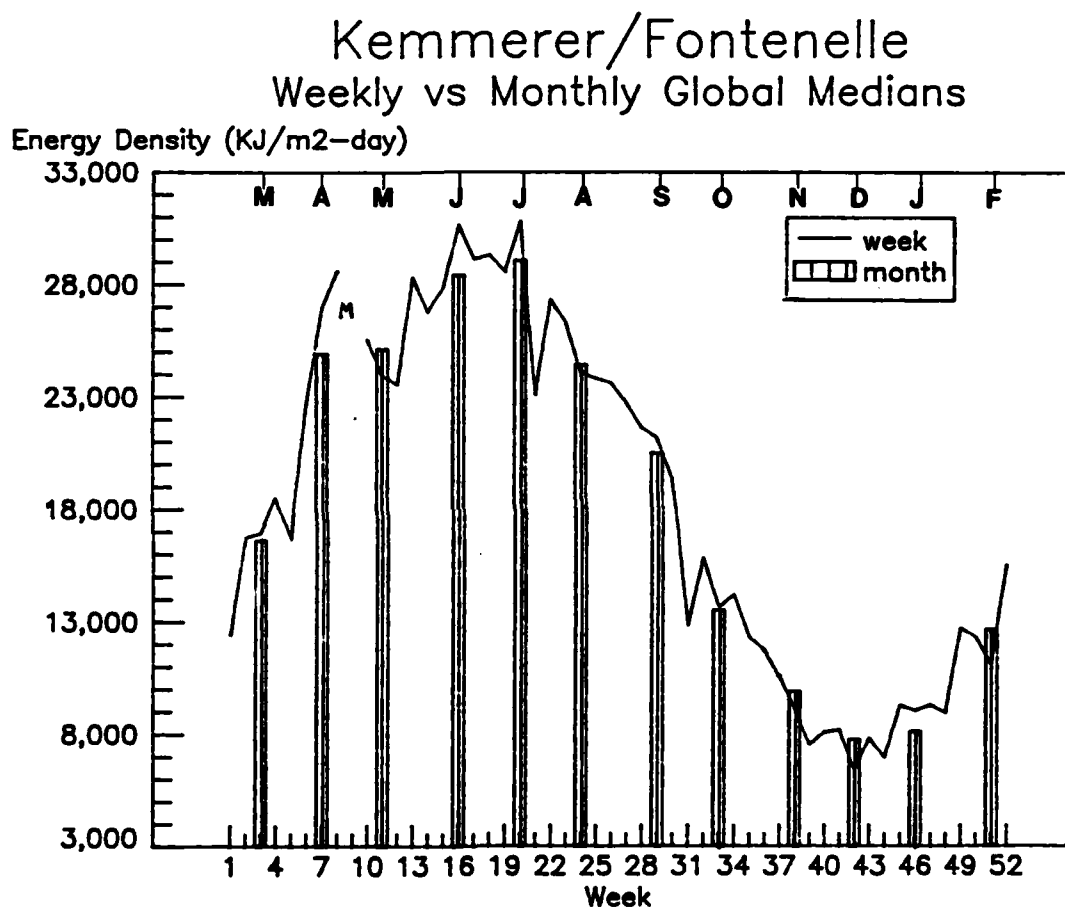
Figure 29. Comparison of weekly versus monthly daily averages.

Logan
Weekly vs Monthly Global Medians

Energy Density (KJ/m2–day)
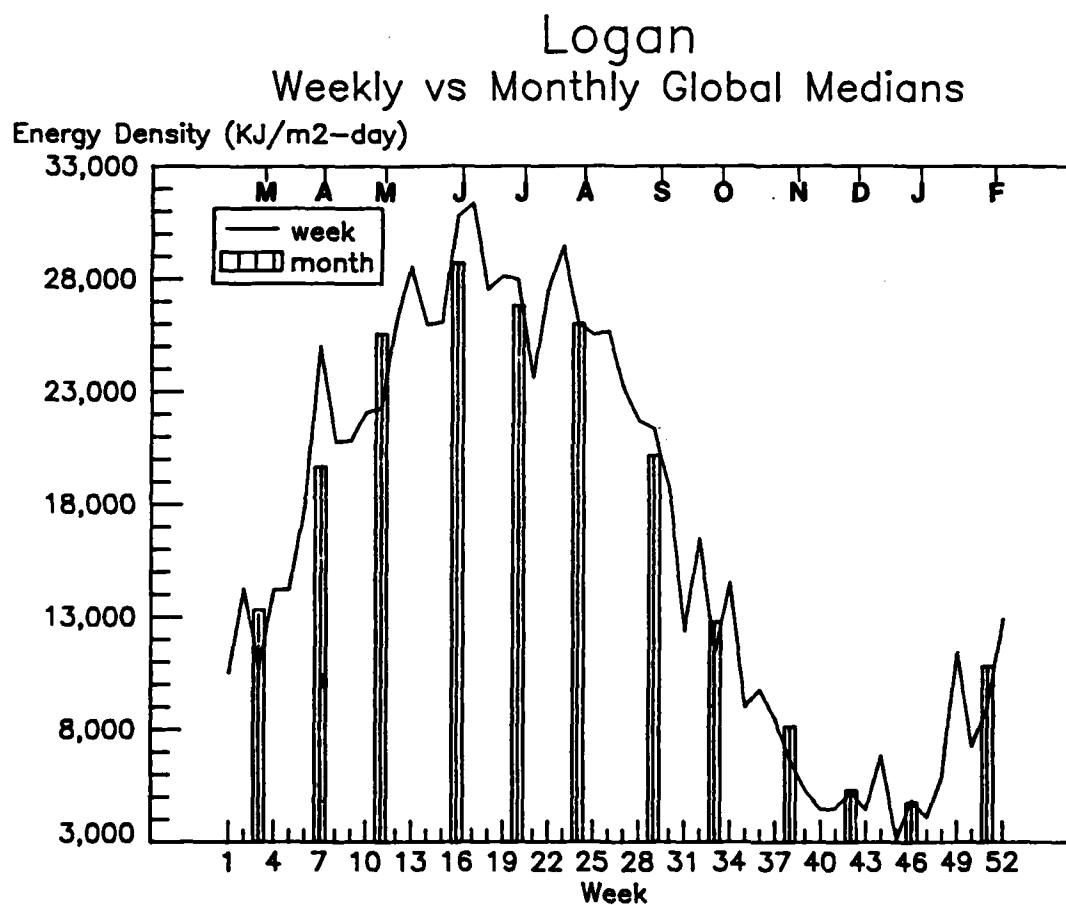
Figure 30. Comparison of weekly versus monthly daily averages.

Lucin
Weekly vs Monthly Global Medians

Energy Density (KJ/m2-day)
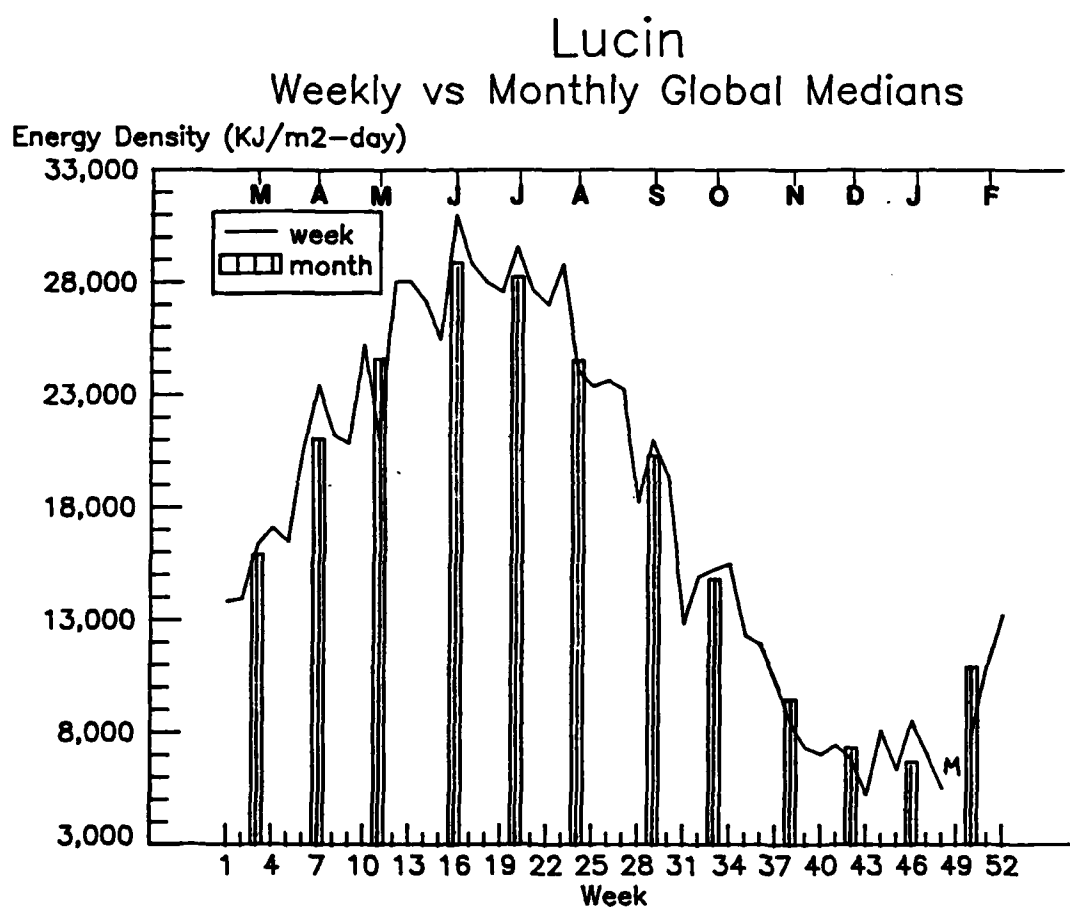
Figure 31. Comparison of weekly versus monthly daily averages.

Salt Lake City
Weekly vs Monthly Global Medians
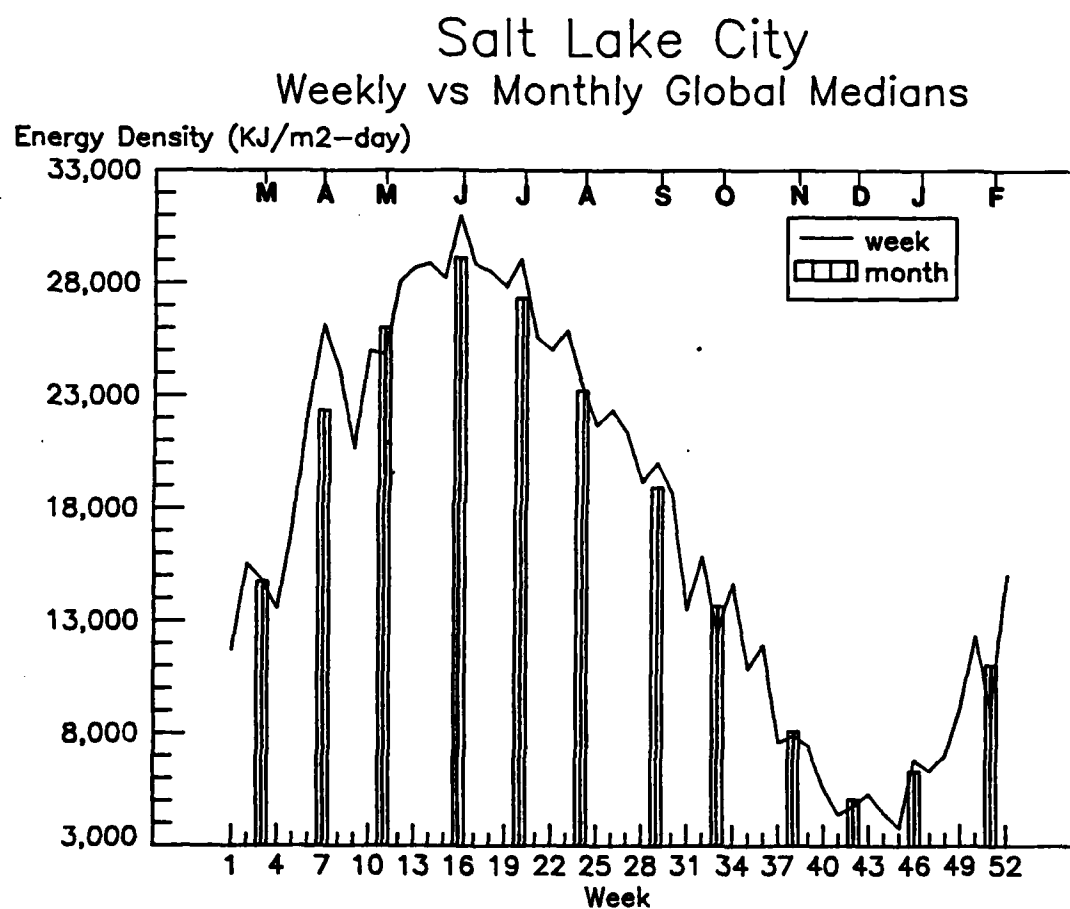
Figure 32. Comparison of weekly versus monthly daily averages.

St. George
Weekly vs Monthly Global Medians
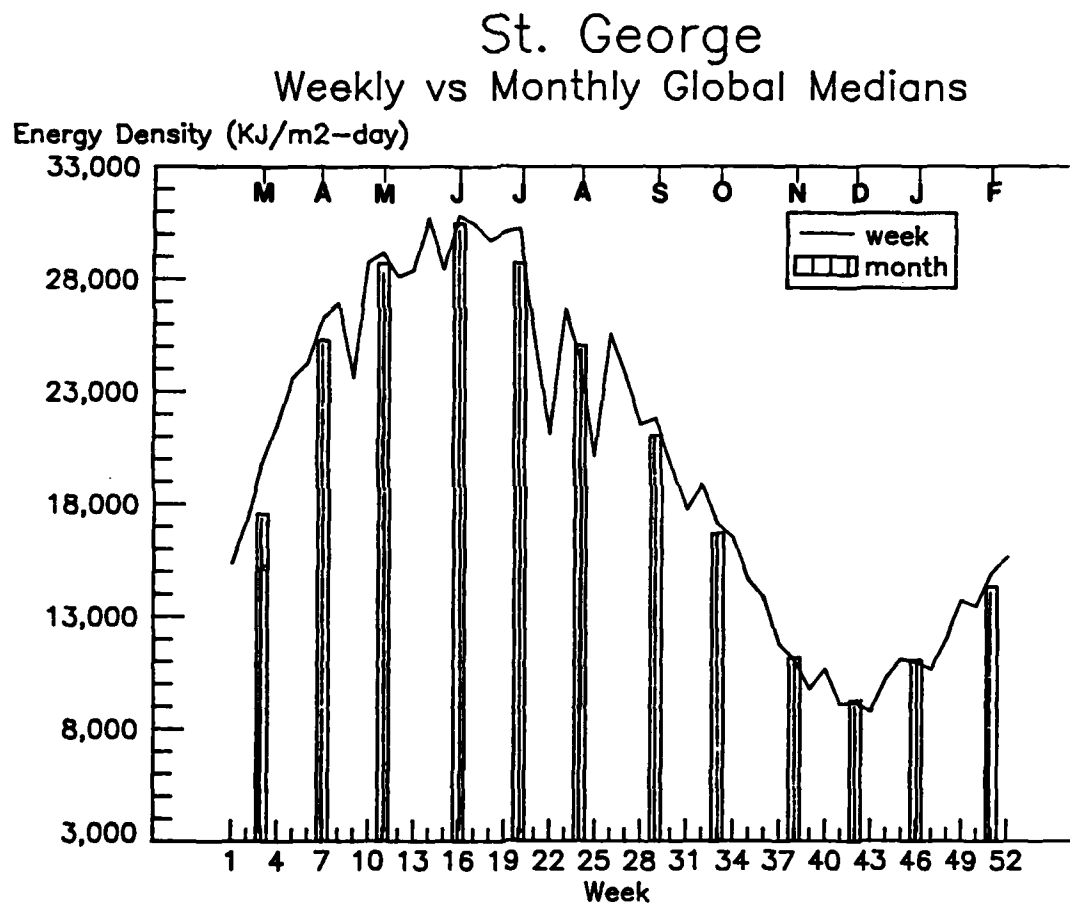
Figure 33. Comparison of weekly versus monthly daily averages.

Distribution of Irradiance

The ten stations provide enough information to produce maps of greater detail than are available from the current solar energy atlas (SERI, 1981). A set of maps (Figure 34 through Figure 45) are produced which contain monthly average global irradiance values. From the results found in the previous discussion, the median is being used as was the best statistic for estimating the average daily value. The maps are not likely to be very representative for mountainous terrain because of varying topographical character-istics that affect irradiation. Therefore, isopleth lines are dashed over the mountain ranges to indicate that discontinuity exists in these high elevations.

Examining the monthly solar energy maps reveal that a distinct non-typical surface irradiance distribution pattern occurs in Utah. The normal latitudinal (north-south) variation or gradient is altered dramatically by topographical discontinuities in the state. The terrain discontinuities play a major role by modifying the regional weather, which in turn affects the irradiation at the surface. This results in the creation of longitudinal variations of significant proportions in the northern and central latitudes of the state.

The geographic features most affecting irradiance are the Great Salt Lake, Uinta Mountains and the Wasatch Mountain Range and plateau. The Great Salt Lake is large enough to produce substantial lake effect weather phenomena. Its effects, however, are confined mainly to the southern and eastern sections of the Salt Lake Valley,
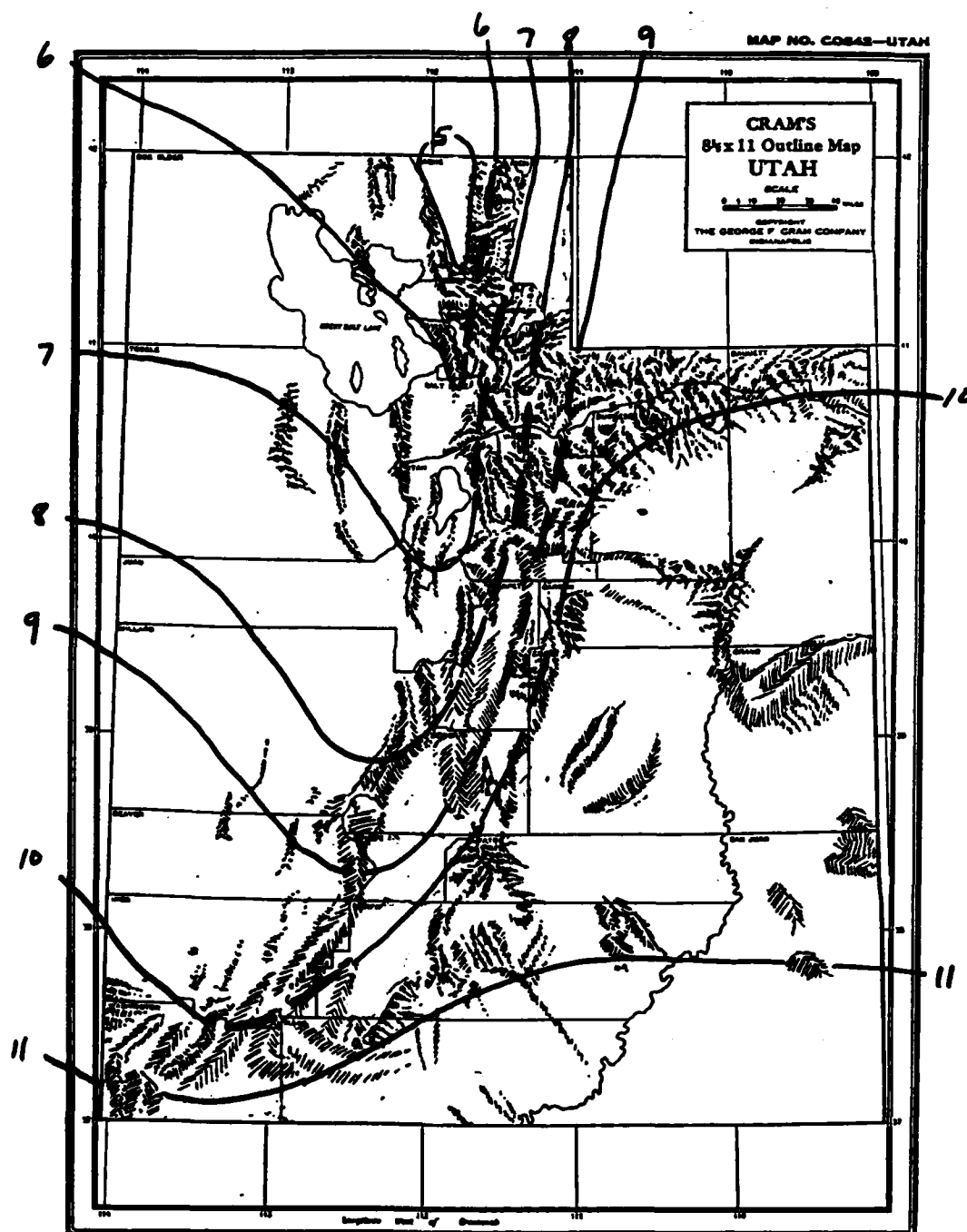
Figure 34. Monthly distribution of irradiance in Utah.
Month of January. Units are: $MJm^{-2} day^{-1}$
Dashed lines are estimates because no data
is available in mountains.
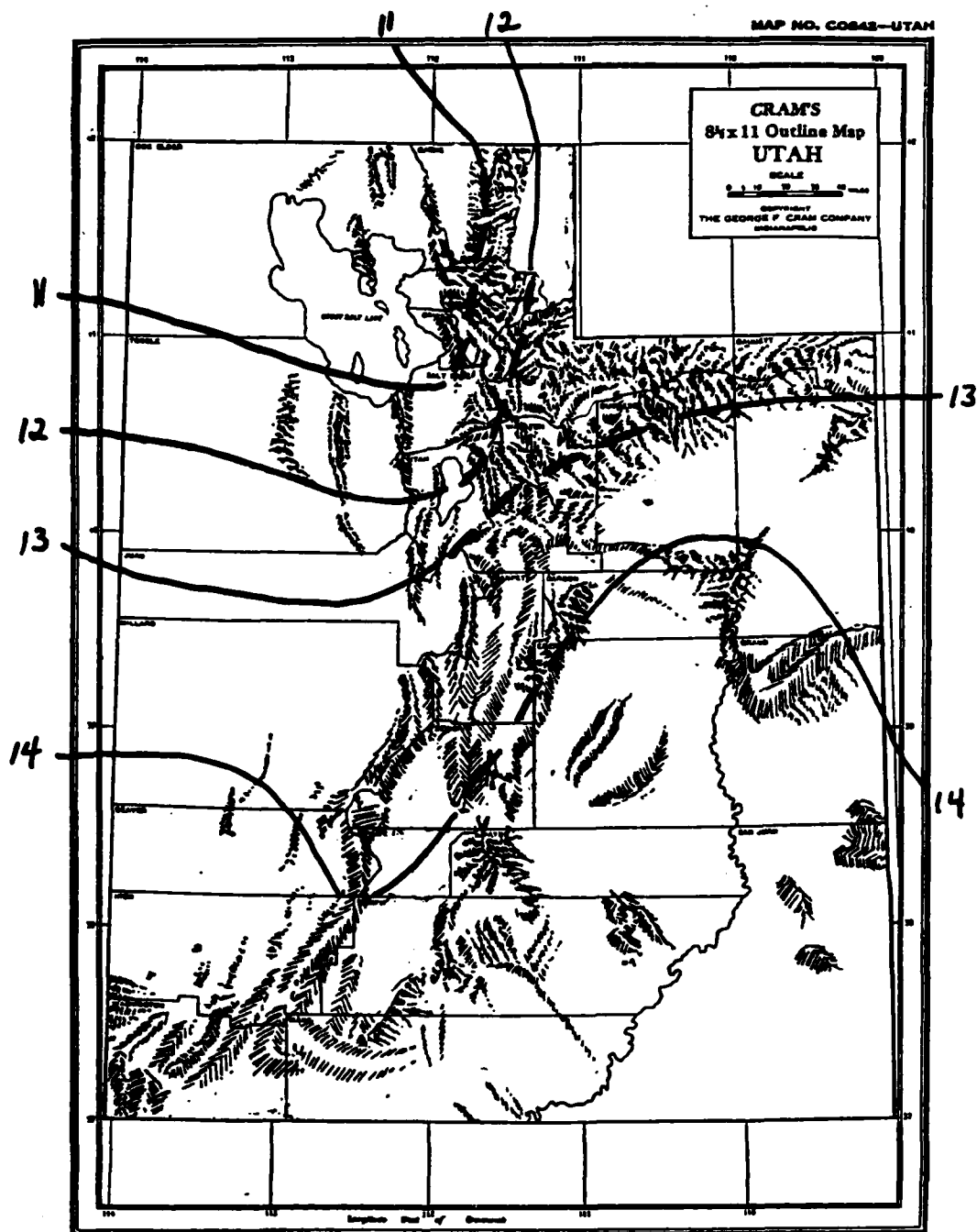
Figure 35.   Monthly distribution of irradiance in Utah.
Month of February.   Units are MJm^{-2} day^{-1}
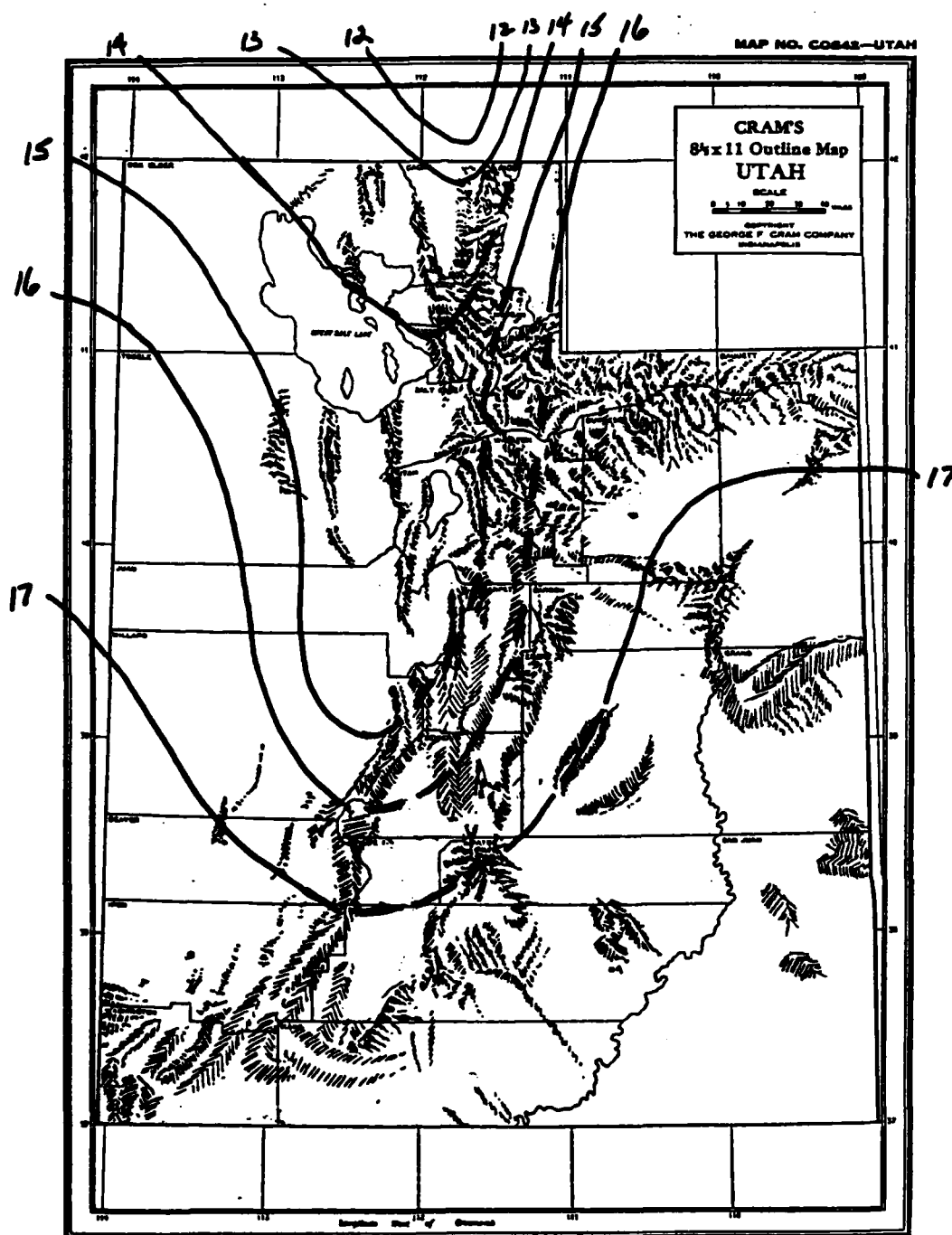
Figure 36. Monthly distribution of irradiance in Utah.
Month of March.   Units are: MJm^{-2} day^{-1}
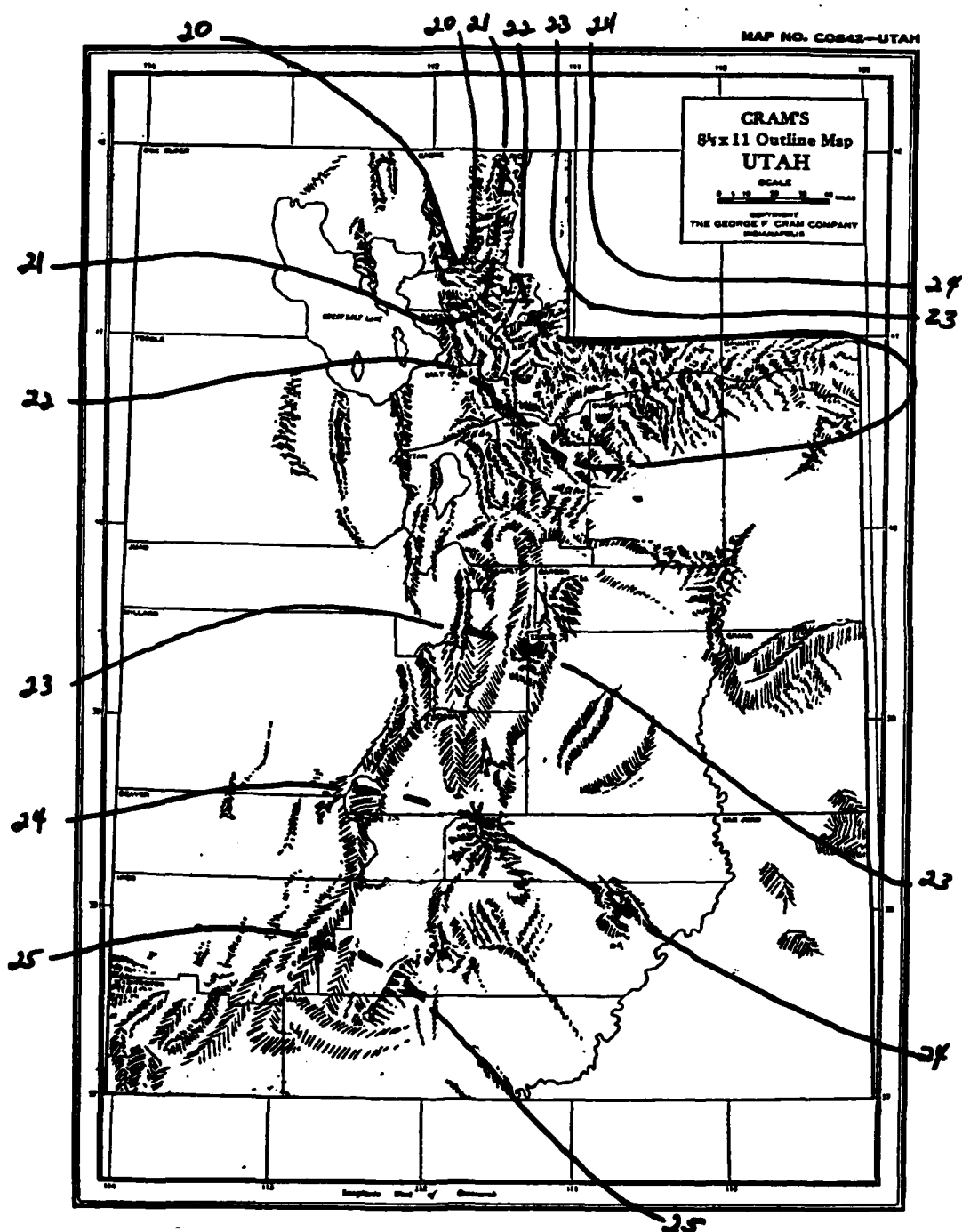
Figure 37.   Monthly distribution of irradiance in Utah.
Month of April. Units are: $MJm^{-2} day^{-1}$
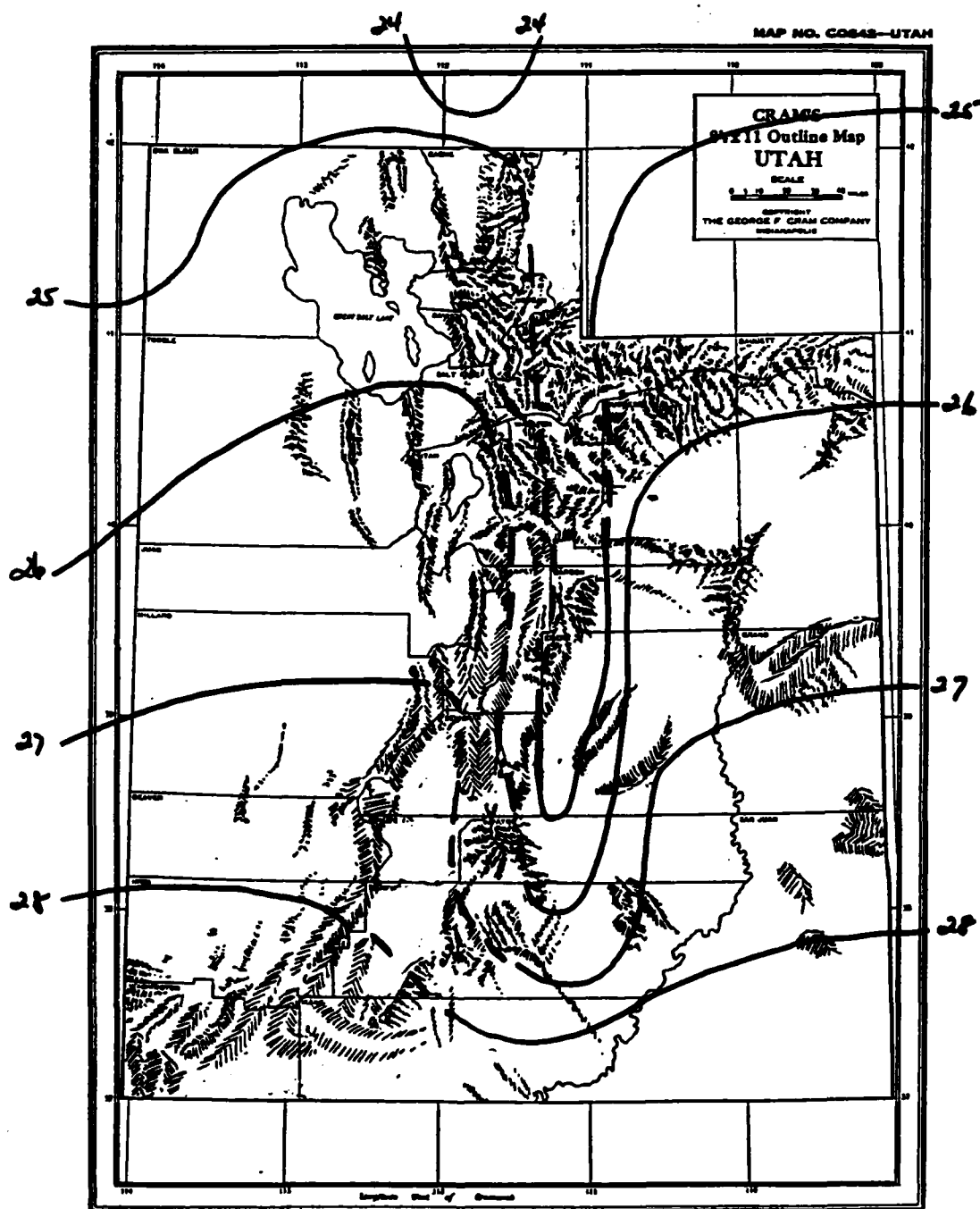
Figure 38. Monthly distribution of irradiance in Utah.
Month of May. Units are: MJm^{-2} day^{-1}
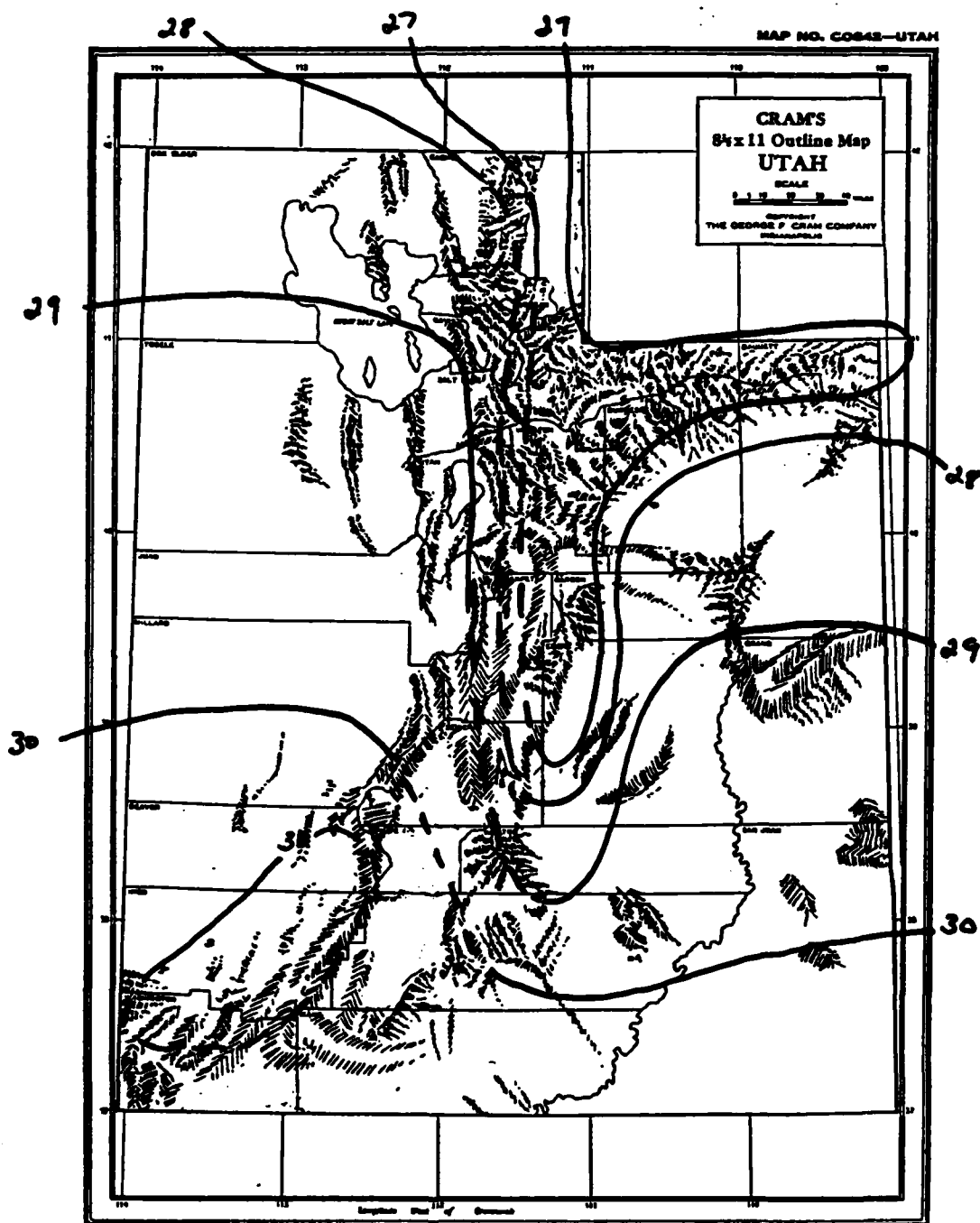
Figure 39. Monthly distribution of irradiance in Utah.
Month of June. Units are: MJm^{-2} day^{-1}
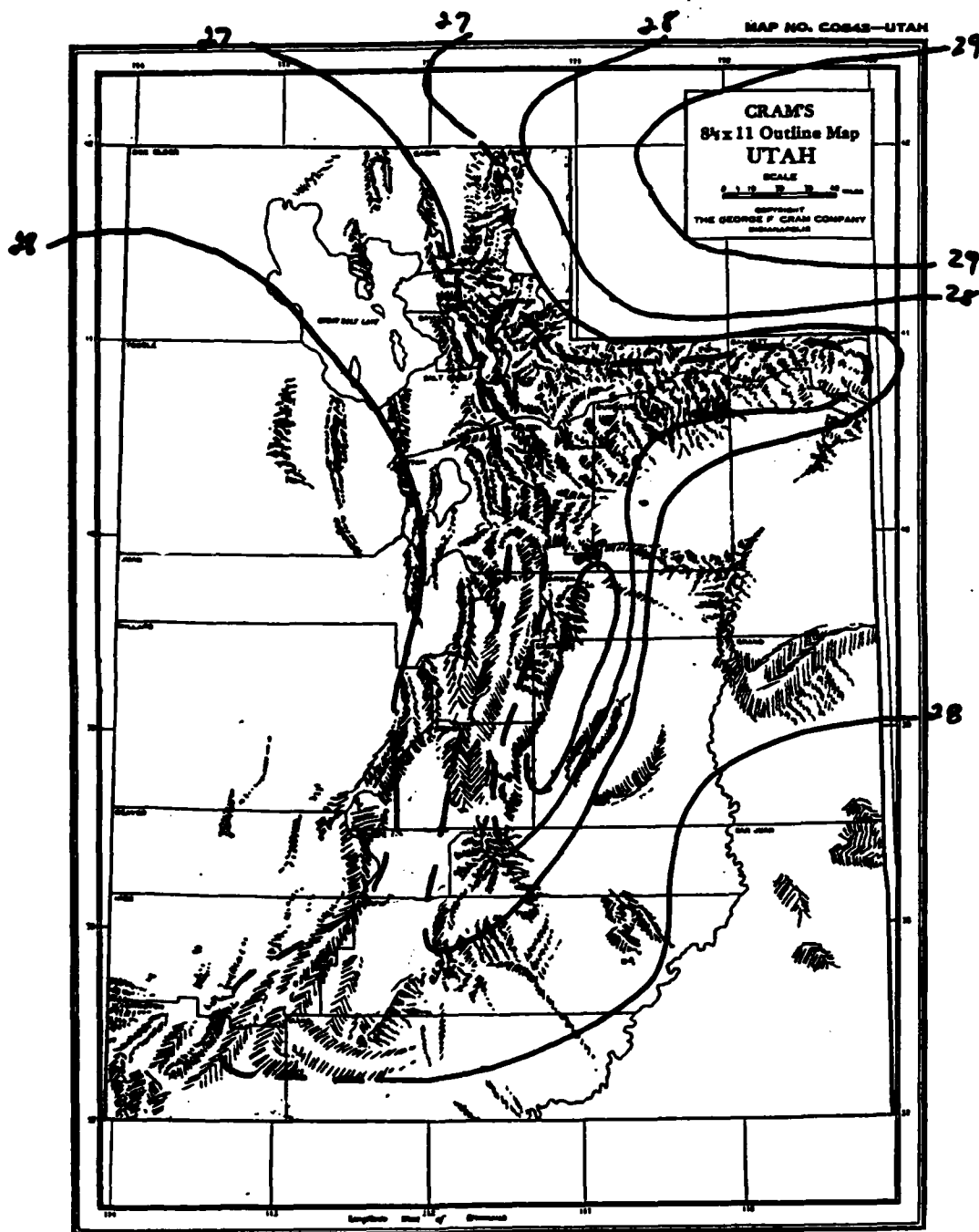
Figure 40.   Monthly distribution of irradiance in Utah.
Month of July.   Units are: $MJm^{-2} day^{-1}$
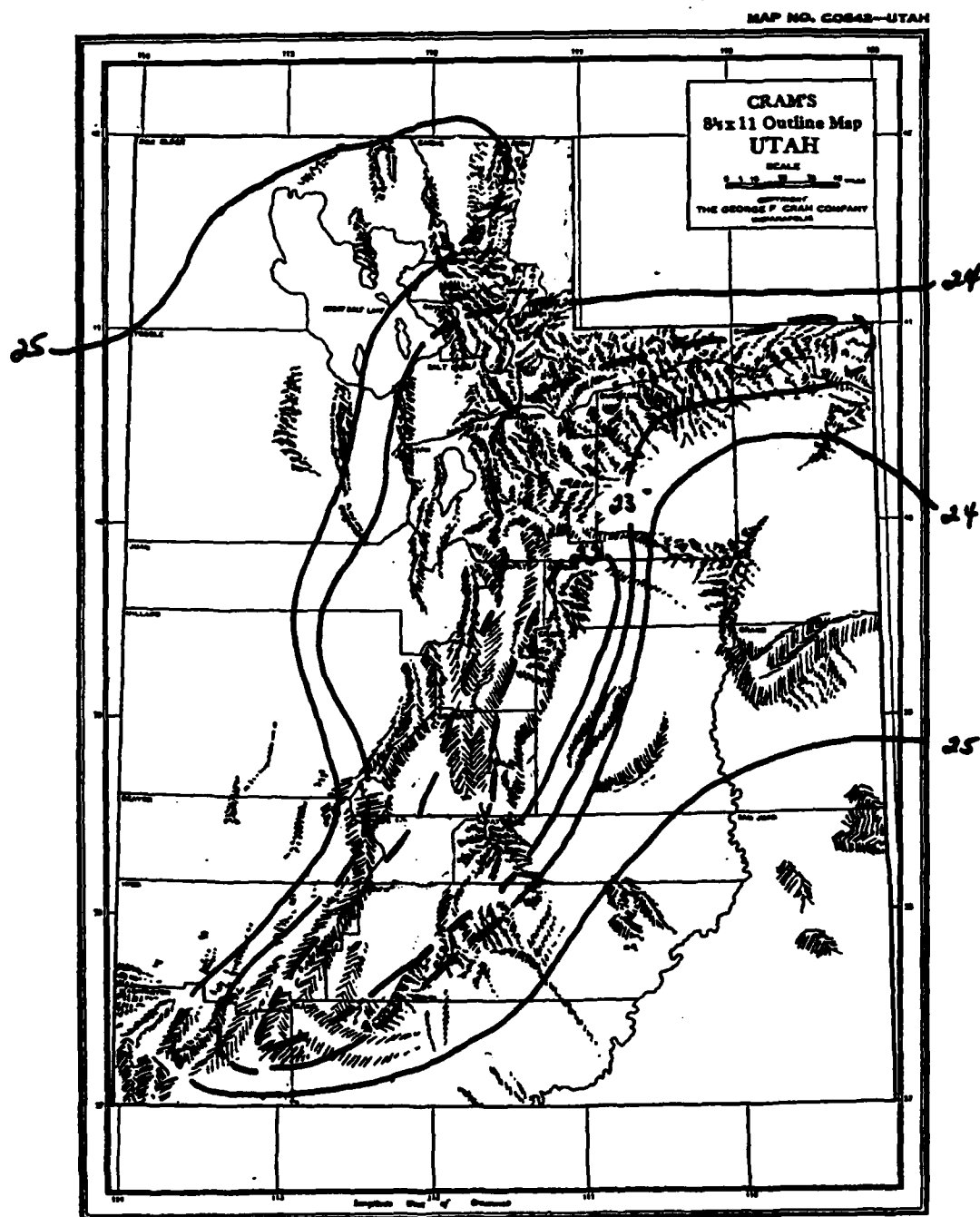
Figure 41. Monthly distribution of irradiance in Utah.
Month of August. Units are: $MJm^{-2} day^{-1}$
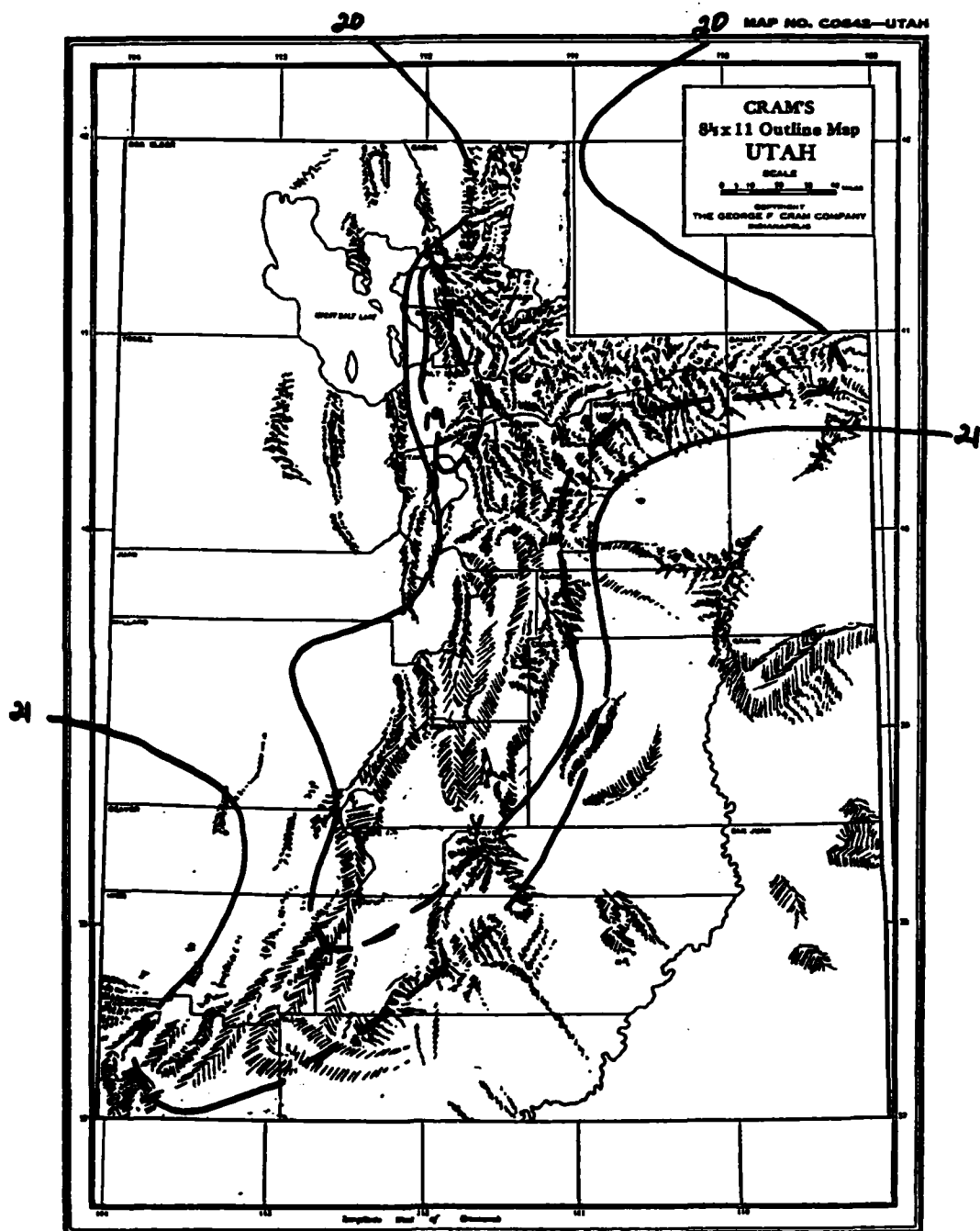
Figure 42. Monthly distribution of irradiance in Utah.
Month of September. Units are: MJm^{-2} day^{-1}
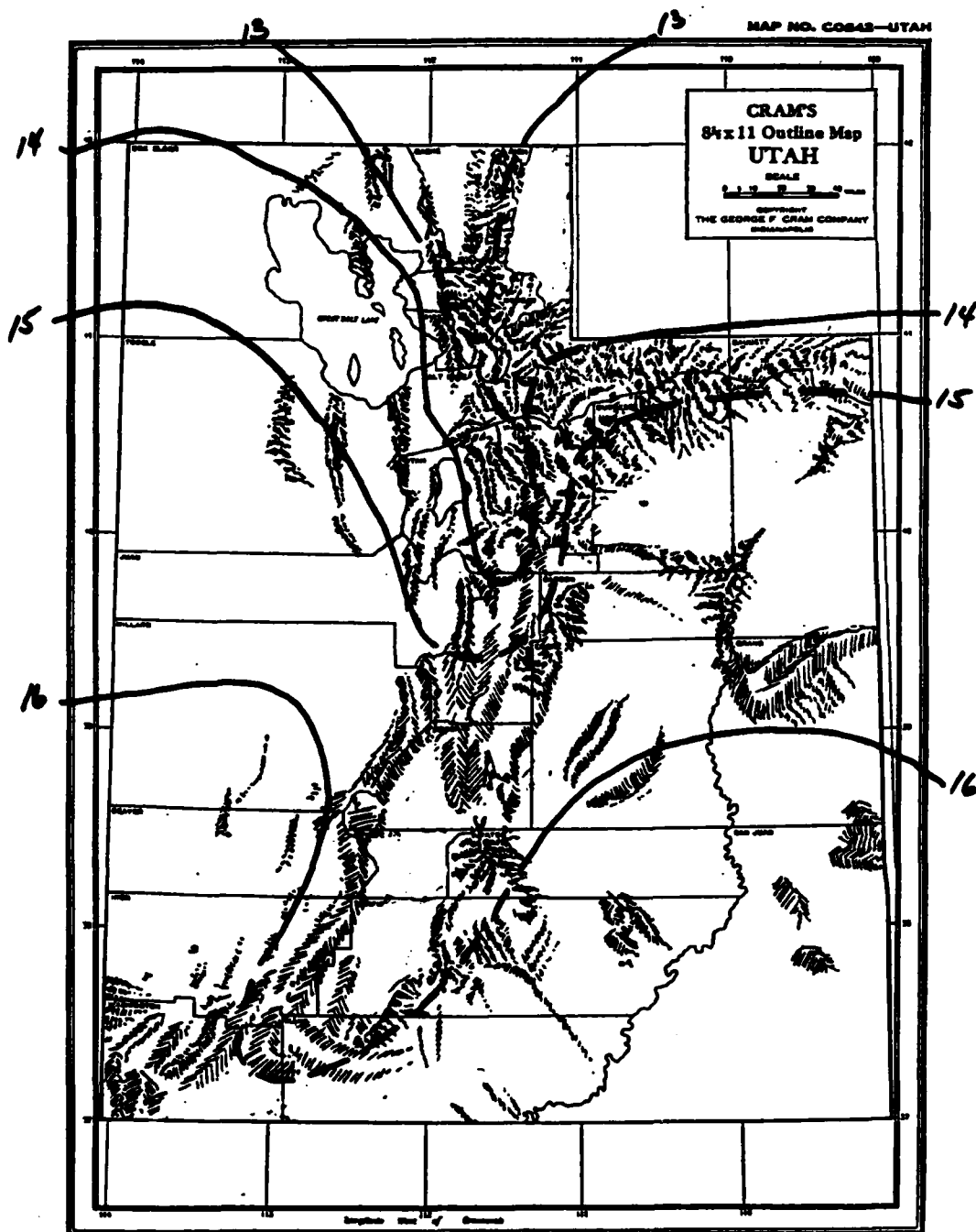
Figure 43. Monthly distribution of irradiance in Utah.
Month of October. Units are: MJm^{-2} day^{-1}
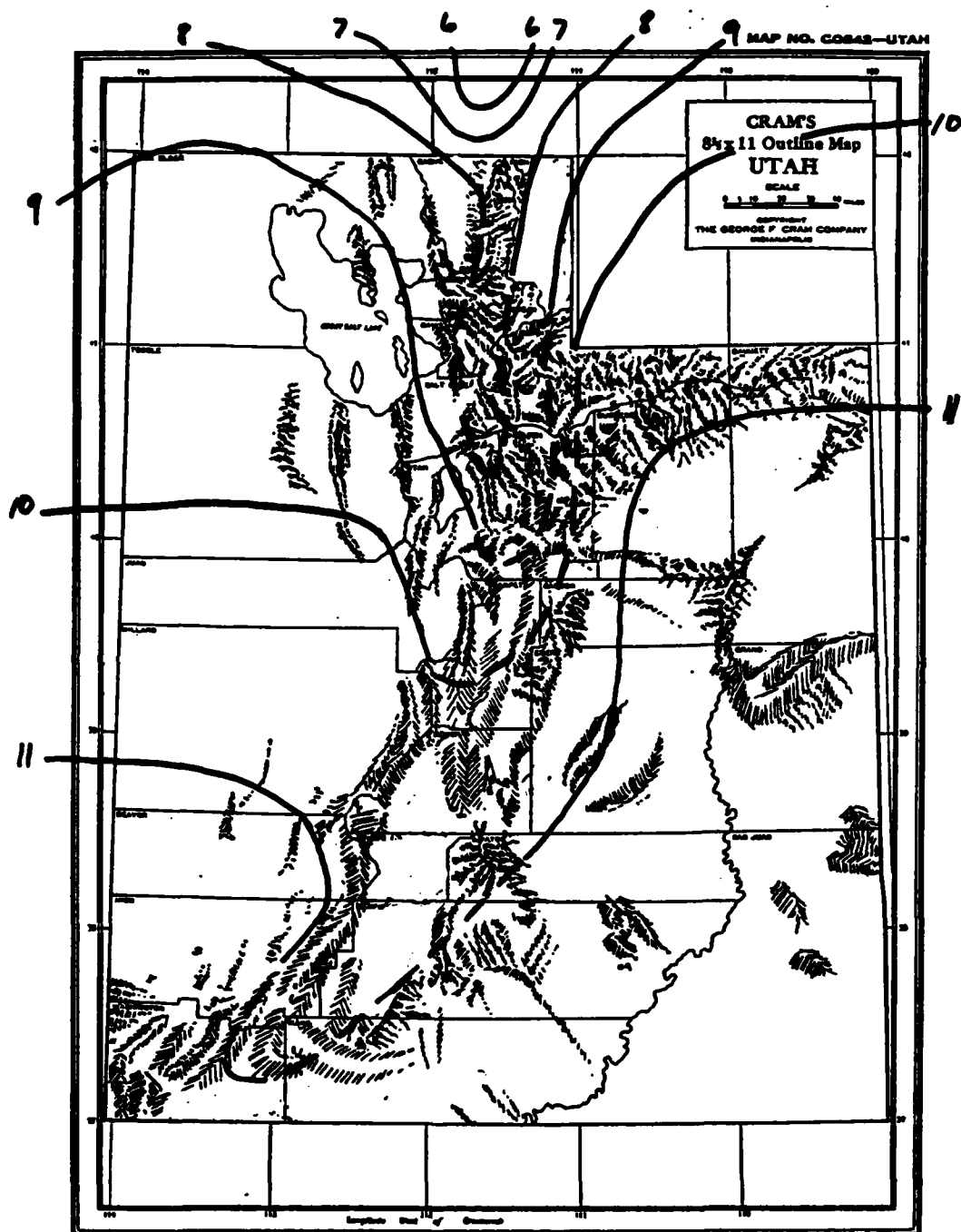
Figure 44. Monthly distribution of irradiance in Utah. Month of November. Units are: $MJm^{-2} day^{-1}$
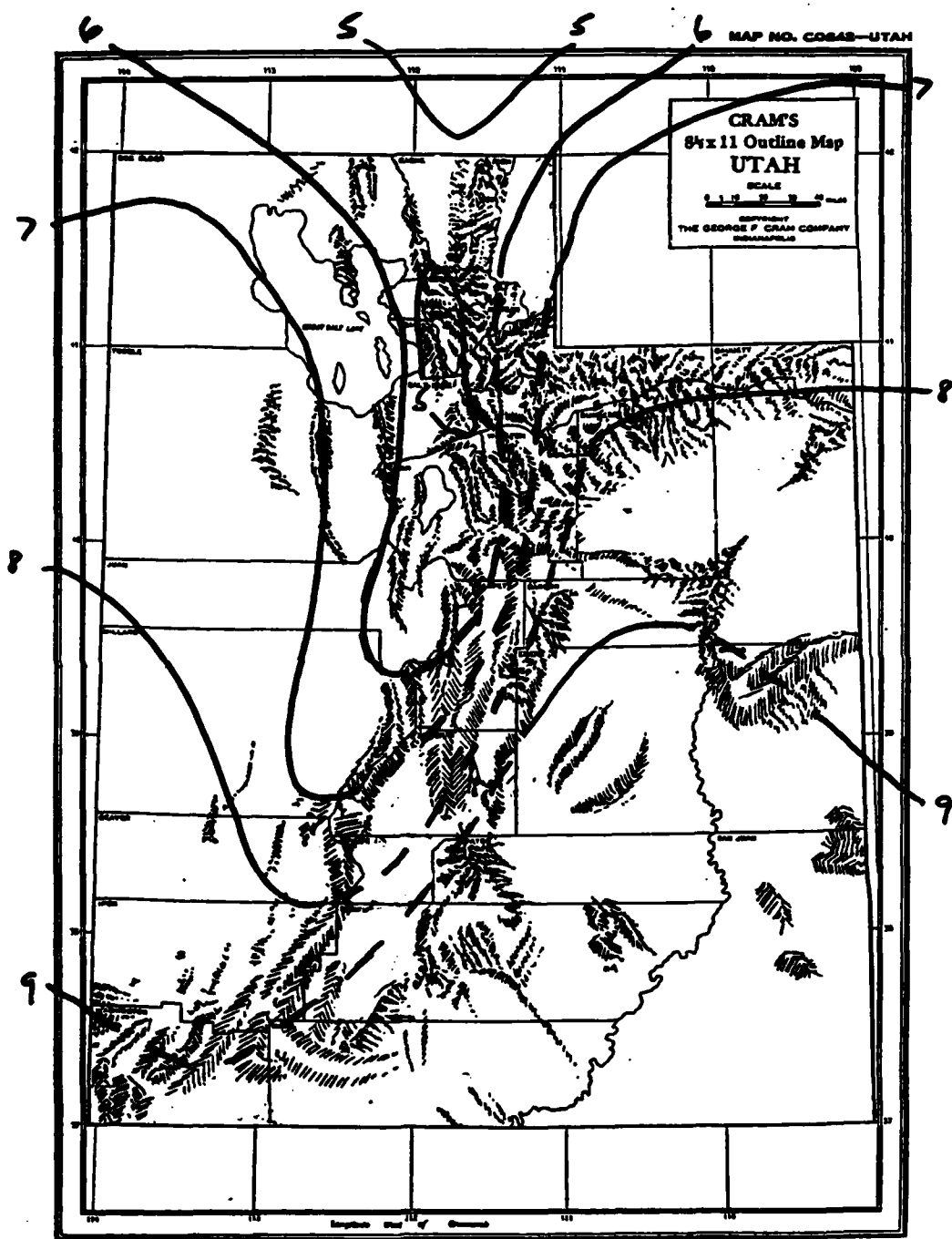
Figure 45. Monthly distribution of irradiance in Utah.
Month of December. Units are: MJm^{-2} day^{-1}

which is a relatively small geographic area. Late fall and early winter are when the lake effect clouds are most prominent. The great influence on local weather is most strongly illustrated on December's map. The increased cloudiness can only be attributable to the lake's existence which causes the Salt Lake area to have the lowest radiation values in the state. More details about the lake effect are explained in a later paragraph.

The Uinta Range is residence for Utah's highest mountains. It is located in the northeast corner of the state bordering south-western Wyoming. The ability of these mountains to greatly alter the radiation distribution pattern is restricted for two reasons. First, they are located behind or east of the Wasatch range where it is subjected to weather shadowing effects. The second reason is that the mountain range is oriented east and west which allows the predominant weather systems to flow parallel to the range without creating many orographic effects on the high plateau to the north and the basin to the south. What these mountains appear to do effectively is prevent the northward advance of tropical moisture and clouds into southwestern Wyoming during the summer. July's map supports this conclusion by the fact that the highest daily average irradiance measurements are found north of the range.

The single most important terrain feature is the Wasatch Mountain Range. When referring to this range, it also includes a composite of other small ranges and the Wasatch plateau. Collectively, they form a narrow, north-south oriented range that nearly bisects the entire state. The mountain range's height and

almost perpendicular orientation to the predominant air flow,
constitute a considerable obstacle to weather systems. This
barrier produces orographic effects which modify the general weather
and causes the normal latitudinal distribution of insolation to
be displaced. This is evidenced by a U-shaped distortion or
troughing of the energy values that appear on nearly every map.
One should note that the troughing does not remain stationary nor
do the longitudinal gradients remain the same. Rather, the
troughing adjusts periodically as seen by the changes in location
and size on the different monthly maps.

The migrating trough of low energy values to the north and
south, approximately follows the latitudinal progression of the
polar jet stream as it moves over the state. In the early fall,
weak frontal systems begin invading into the northern portion of
the state. October's map reflects these incidents as a trough has
started developing over the northern Wasatch range. By November,
the trough is well developed. Active storm systems are more
frequently flowing into the state and are beginning to penetrate
into Utah's southern regions. With these fronts, accompanies
cold, potentially unstable air. When this air flows over the
relatively warm Great Salt Lake, it creates lake effect clouds.
These clouds further reduce surface irradiance in the Salt Lake
Valley and are a major factor producing the sharp trough over
this area.

December's map contains the lowest average daily radiant
energy values for the year at every location except in the Cache

Valley. Short days, lower sun angles and greater cloudiness are the determining factors causing the low values. During this month, the trough reaches its furthest southern extent as vigorous frontal systems frequently pass through the state. The lowest values are found over a small area to the south and east of the Great Salt Lake for reasons that were previously mentioned. The trough has also grown wider and its center is positioned slightly west of the Wasatch Range. The widening trough, indicates a westward expansion of cloudiness that is being caused by the mountain range. Explanations for the increasing cloudiness into the western valleys have been formulated from the author's personal weather observation experiences while a meteorologist working over three years in Utah.

During the cold weather months, frontal systems moving into Utah have cloud bases and saturated water vapor layers which are much lower (two to three thousand feet) than the ridgetops of the Wasatch Range. When the moisture layers approach the range, orographic lifting causes the saturated layers to condensate, forming additional clouds. As all these low cloud layers encounter the mountain barrier, they are slowed down considerably or sometimes stalled in their eastward progression. This "traffic jam" of clouds causes a backward or westward stacking of low level clouds. They will usually linger over the western valley, trapped by the mountain range, until drier, post-frontal air flows over the valley. As mixing occurs the clouds dissipate. This can sometimes take up to several days, before skies become clear.

Another type of cloud formation induced by the mountains

occurs when snow covers the ground and a strong high pressure system builds over the western United States. Subsiding air alot along with the horizontal mountain barriers prevents air from escaping out of the valleys. Cold, dense air flowing down off the mountain slopes and eastern plateaus settles into the basins, intensifying the already formed atmospheric inversion. In the stagnant valley air, water vapor from sublimating snow and condensation nuclei from industrial and automobile pollutants are accumulating. When the ambient air cools, reaching the dew point temperature, condensation occurs forming fog. These valley fogs are known to be very persistent and can become quite thick. Once they form, they will remain until the inversion is dissipated; usually by the onset of an approaching cold front. This kind of weather condition is common during December, January, and into early February. It provides the additional cloudiness that widens the trough in January and also causes the Cache Valley to claim the state's lowest average values of the year. Valleys east of the Wasatch range rarely experience these kinds of weather episodes, because they are actually plateaus and higher evaluation basins which drain into the lower western valleys.

The month of February illustrates the latter stages of winter. The trough is shown retreating northward because frontal systems are no longer frequently invading into Utah's Dixie region. Snow cover on the western valley floors has begun melting, exposing the ground thus reducing the occurrences of valley fogs.

In March, the trough is purely defined by the penetration of

frontal systems. Storms occurring during this motnh are generally weaker and tend to be slowed down traversing the mountain range. The stacking effect still applies because the fronts will have sufficient low clouds which back up and keep the trough located to the west of the range.

April's map shows a near latitudinal gradient for most of the state. The light troughing in the far northern region, outlines the area that continues to be susceptible to polar frontal systems. You will also notice that the northern section Wasatch front is an effective weather barrier. Values east of the range are significantly higher indicating a strong weather shadow effect is taking place.

The trough redevelops in May, to shape the radiation regime that exists for the whole summer. Its position has shifted eastward because most cloudiness is occurring above the ridgetops and extending over the leeside plateaus and basins. Clouds are formed orographically as the air travels over the highlands and convectively from heating the mountain slopes. Frontal systems are infrequent and when they do move through the state, rarely are there cloud layers which have bases lower than the mountains. These lower layers now have warmer temperatures and low humidites which raises the height of the condensation level closer to or above the mountain elevations. These cloud layers easily pass over the mountains, preventing any back-up of clouds.

The size and shape of the trough remains nearly the same during the month of June. In July, it strengthens as it reflects increased orographic and connective cloudiness resulting from tropical

moisture moving into the state.

Invasions of tropical moisture are mainly confined to the southern half of the state in August as noted by the weakening trough in the northern region. September is another transition month with the trough being very weak and orographic and convective cloudiness occurring about the same on either side of the Wasatch range.

CONCLUSIONS

Frequency distributions of daily insolation are generally skewed. The median was determined to be a more realistic statistic than the mean to measure the central tendency (average) of the distribution. Variability was expressed by graphing the maximum, minimum, median, 25th and 75th percentiles by month for each station.

Monthly averages were found to be adequate when estimating daily energy values for most months of the year except during the spring and fall. Transitioning weather patterns and rapid day length changes cause radiation reception to vary greatly during these few months. A weekly average should be used at these times to more accurately estimate the daily energy received.

Solar radiation measurements obtained from the Utah Solar Network indicate that non-homogeneous terrain has a noticeable effect on the distribution of global radiation. Orographic induced cloudiness displaces the normal latitudinal gradient of irradiance along the Wasatch Range and causes a trough of low radiation values to be formed near and over the mountains. The radiation maps suggest that spatial variability can be significant at areas adjacent to a mountain range. The trough's presence is seen on nearly every map. However, it is not stationary, as it migrates both north-south and east-west during the course of a year.

It is hoped that the presentation of information in this paper will encourage investigators to pay close attention to appropriate statistics and time scales used for determining expected values, and inform users of the solar energy atlas and insolation manual about the inherent potential errors contained in these references.

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APPENDIX

Table 3. Monthly and selected spring and fall weekly solar
          irradiance statistics.

MONTH	MEAN	STDEV	MAXIMUM	MINIMUM	MEDIAN	25%	75%
				--Delta--			
Mar	14914	5326	23877	2095	14811	10661	19669
Apr	21779	5685	29286	6775	23232	18418	26617
May	25150	5712	32004	7968	26926	22262	29284
June	28226	4533	33197	11504	29882	26436	31168
July	27028	4043	32468	14874	28376	24577	30132
Aug	22992	4025	28997	12496	23679	20879	26155
Sep	17807	5526	24418	2698	19685	14615	21708
Oct	14178	4100	20185	2357	15408	12145	16940
Nov	9897	3205	14239	1767	10643	8426	12420
Dec	6662	2447	10773	2756	6388	4565	9235
Jan	7371	3242	13111	1854	7737	4328	9917
Feb	12576	3541	18351	3654	13662	10340	14932

WEEK	MEAN	STDEV	MAXIMUM	MINIMUM	MEDIAN	25%	75%
1	10921	4381	20134	2095	10661	8572	13851
2	14821	4326	20728	5589	15319	11665	18936
3	14637	5163	23877	6254	14981	10465	18739
4	17053	5381 ·	23818	4786	18245	13616	20273
5	18200	4932	25054	7001	18418	15896	22863
6	20718	5601	27405	7937	21829	17625	25426
7	23528	5467	27847	8978	26150	20915	27087
8	22853	5652	28910	6775	25205	19529	27495
9	21730	5004	29266	12483	21742	19032	26571
28	18469	4477	24079	9690	18819	16668	21472
29	19542	3344	22406	11518	20830	19353	21296
30	16862	5869	22649	4297	18876	13570	21708
31	13060	5737	20185	2698	13737	10962	18181
32	16935	3067	19952	11993	18079	12555	19382
33	15332	2542	18105	11248	16501	13384	17320
34	14539	2926	17196	7028	15760	12489	16653
35	10862	4911	15861	2357	12031	5232	15400
36	12196	2603	14239	4118	13025	11669	13818

Table 4. Monthly and selected spring and fall weekly solar
irradiance statistics.

MONTH	MEAN	STDEV	MAXIMUM	MINIMUM	MEDIAN	25%	75%

--Altamont--

MONTH	MEAN	STDEV	MAXIMUM	MINIMUM	MEDIAN	25%	75%
Mar	16336	4408	24448	7448	16953	12631	19907
Apr	20832	5719	28727	7807	21932	17551	25103
May	25171	5826	32812	10605	26079	19902	30214
Jun	26679	6127	33620	10644	27873	21671	35159
July	25745	7142	33585	7570	26711	20626	32112
Aug	22710	4696	29338	10772	23671	18576	26381
Sep	19423	4693	24939	2322	21073	17097	22593
Oct	14403	3326	19389	5256	15337	11987	16624
Nov	10747	2551	14495	3427	11437	9467	12349
Dec	7359	3085	11404	1968	8569	4686	10121
Jan	10054	2409	13644	5738	10618	8167	12237
Feb	13381	2310	17420	5916	13720	12295	14534

WEEK	MEAN	STDEV	MAXIMUM	MINIMUM	MEDIAN	25%	75%
1	16758	3536	21172	10407	17767	14629	19022
2	17103	4071	20329	9033	18955	16953	19633
3	15174	4425	22160	10649	14177	11270	16760
4	17380	6025	24448	7448	19229	13681	19765
5	16275	7194	26124	7807	15344	12673	17551
6	19916	4920	25956	10432	21600	18116	22317
7	23677	6032	28332	8494	26963	22617	27775
8	21147	4075	27893	13879	21136	18469	23362
9	18960	6012	28727	10094	20323	13280	22561
10	27734	3678	31745	18850	28850	26750	29646
28	20638	4109	24575	10679	22644	17559	23309
29	21008	2290	22881	15223	21632	21157	22254
30	16871	5752	22319	2322	18478	15754	20936
31	15164	4843	20447	5256	16429	11858	18406
32	16666	2173	19389	12338	17027	14925	18498
33	14559	2658	18194	10387	15546	13228	16062
34	12997	3474	16850	8263	13662	9391	15948
35	13481	2441	15776	9138	14581	10874	15293
36	12277	1708	14495	9305	12811	11678	13181

Table 5. Monthly and selected spring and fall weekly solar
          irradiance statistics.

MONTH	MEAN	STDEV	MAXIMUM	MINIMUM	MEDIAN	25%	75%
			--Cedar City--				
Mar	16570	5580	25350	3883	17587	12436	20860
Apr	23340	5532	29816	5559	25466	20275	27677
May	26600	5718	33172	8677	28604	22075	31170
June	28906	5763	34957	8966	31325	27420	32621
July	25786	6146	33528	9059	27843	22091	30704
Aug	21715	5569	30504	7545	22385	18333	25729
Sept	19169	4806	25747	5899	20368	15816	22987
Oct	14733	3951	20443	2709	15879	12497	17469
Nov	10524	3310	15091	2198	11076	8634	13135
Dec	7977	2765	11396	1686	8753	5426	10659
Jan	9354	2797	14247	2914	9857	7286	11565
Feb	13598	3280	19638	5445	14307	12137	15231

WEEK	MEAN	STDEV	MAXIMUM	MINIMUM	MEDIAN	25%	75%
1	14242	4094	20810	4882	14265	11397	18417
2	15297	4532	21434	4224	14855	13192	19717
3	17209	5658	24257	6133	18019	11438	22587
4	18169	6258	24378	3883	19673	13591	23805
5	20853	5685	26846	5559	22477	17340	24773
6	22359	5052	27768	8729	24198	17750	26074
7	24589	6086	28643	6679	27597	22153	28134
8	24030	5339	29816	11741	26619	19915	28167
9	23025	5264	29710	8122	23856	19887	26816
28	18725	5232	25267	8979	19183	13839	23783
29	18668	4169	23896	8685	19316	16366	22085
30	18559	4491	23742	7017	20757	25084	21753
31	15620	4304	20858	5899	16390	11910	19668
32	17273	2221	20272	11889	17969	15197	18967
33	14357	4676	19165	3024	16675	9873	17643
34	14747	3513	17625	5466	16652	12796	17250
35	12721	3688	16293	2709	14055	10250	15566
36	12469	3003	15091	5374	14102	9822	14732

TABLE 6. Monthly and selected spring and fall weekly solar
irradiance statistics.

MONTH	MEAN	STDEV	MAXIMUM	MINIMUM	MEDIAN	25%	75%
--Ferron--							
Mar	16339	5174	24171	3541	16694	12853	20375
Apr	22695	4835	29706	8691	23475	19208	26585
May	23848	5569	31729	11588	24806	20156	28797
June	26565	5002	35196	12511	26939	32061	30883
July	24826	5554	32370	7436	24875	21958	29370
Aug	21343	4519	29639	8740	21943	18922	24684
Sep	18249	5196	25632	4340	19739	14582	21993
Oct	14915	4132	20023	3624	15993	14186	17386
Nov	10172	3177	14637	1616	10627	8729	12297
Dec	8407	2367	11347	1894	9286	6860	10163
Jan	10296	2544	14056	2385	10857	8781	12339
Feb	14110	2686	18473	4890	14473	12989	16127

WEEK	MEAN	STDEV	MAXIMUM	MINIMUM	MEDIAN	25%	75%
1	14059	4741	20336	3541	15037	10092	18447
2	15926	4639	21299	5610	17433	12501	19765
3	16619	5106	23241	7169	16231	11901	21887
4	17933	5796	24171	4611	19615	13579	23308
5	19736	4798	26962	8691	18742	15463	23639
6	22020	4759	27843	9900	22059	19766	26246
7	23875	4971	28376	13244	25880	20925	27828
8	23282	5011	29706	10782	23512	20030	27313
9	21826	4424	28550	11588	22479	18819	26552
28	19619	3928	24678	11904	19620	16985	23621
29	18404	4469	23430	6198	20369	15362	21058
30	17034	4967	23380	8191	18423	13679	21330
31	13683	5079	20864	4340	15796	10585	16723
32	17545	1674	19791	14186	17252	17113	18931
33	16655	1084	17977	15050	16473	16235	17605
34	14651	1994	17386	12197	14610	13410	16344
35	9279	4698	15616	3624	8645	7593	15006
36	13304	1314	14637	10497	13632	13069	14096

Table 7. Monthly and selected spring and fall weekly solar
irradiance statistics.

MONTH	MEAN	STDEV	MAXIMUM	MINIMUM	MEDIAN	25%	75%
				--Grace--			
Mar	12099	4210	20932	3809	11374	9160	15196
Apr	19339	6486	29613	6049	20275	14449	24640
May	22294	7793	32695	4690	23924	16275	29361
June	25389	6384	33539	6021	26747	21586	30560
July	21670	5927	33979	8251	27964	24266	30506
Aug	23222	5276	29285	7378	24814	20998	26953
Sep	17242	5666	24880	1842	19447	13220	21172
Oct	11441	4396	19055	1486	12532	8115	15219
Nov	6831	3491	12779	810	5938	4007	10382
Dec	5065	2264	9769	870	4810	3442	6886
Jan	6671	2096	12072	3893	6092	5109	8376
Feb	10975	3220	16506	3600	11828	8439	13604

WEEK	MEAN	STDEV	MAXIMUM	MINIMUM	MEDIAN	25%	75%
1	10291	3172	16259	5956	10453	6962	12700
2	11710	4960	20163	3809	11264	7928	15625
3	13202	4512	20745	7729	12342	10071	17752
4	13757	3977	20932	8934	12648	9903	17956
5	13535	5515	22005	6049	13150	8419	19460
6	17408	5788	26041	6488	18318	13563	23129
7	22009	5051	27415	11377	22250	19512	26873
8	20008	8443	29613	6964	21342	12407	28343
9	20155	4919	28955	14336	18502	15992	24640
28	17999	5715	23787	4708	20164	16869	21873
29	18555	4007	22236	8669	20577	15765	21172
30	15474	5571	21494	1842	17221	12587	19911
31	12476	5194	19577	3702	12314	7259	17716
32	12827	4298	17775	4698	14358	8567	16700
33	11309	4480	16242	2041	10879	8410	15737
34	12347	3857	15384	2246	13775	12471	15037
35	9008	4272	14428	1486	10428	5485	12176
36	9592	3284	12779	1239	11141	8474	12146

Table 8. Monthly and selected spring and fall weekly solar
irradiance statistics.

MONTH	MEAN	STDEV	MAXIMUM	MINIMUM	MEDIAN	25%	75%
			--Kemmerer/Fontenelle--				
Mar	15684	4063	22503	6156	16609	12662	18550
Apr	23247	5640	29427	10151	24904	19165	28268
May	24346	6331	32995	9624	25109	18665	29944
June	26605	5778	34036	12496	28367	21294	31324
July	26283	6428	34230	10427	29047	21272	31241
Aug	23803	3873	29674	10533	24401	21830	26188
Sep	18334	5770	25511	2609	20488	15746	22397
Oct	12577	3675	18913	3282	13509	9986	15361
Nov	9148	2704	13196	2448	9903	6814	11402
Dec	7325	1931	10616	2860	7755	5743	8845
Jan	8972	1880	12602	5500	9114	7837	10193
Feb	12577	2292	17165	8729	12653	10253	14294

WEEK	MEAN	STDEV	MAXIMUM	MINIMUM	MEDIAN	25%	75%
1	12975	3342	18550	7125	12427	10338	16641
2	14862	5034	20797	6156	16728	9968	18403
3	17157	3452	21754	10109	16947	15589	20599
4	17916	3228	22503	10666	18491	16693	19947
5	17652	5512	25833	10679	16659	13906	24517
6	20508	6377	26855	10151	22664	19165	26318
7	26206	2350	28407	22961	26947	23703	28268
8	25497	5282	29427	16903	28588	17419	28848
28	18671	6156	24175	3868	21603	15359	23231
29	19408	4720	23132	2609	21157	19315	22017
30	17353	4823	22727	3926	19345	15706	20570
31	12821	4324	19525	6052	12819	9986	15783
32	14621	3478	18129	3925	15831	13868	16796
33	12296	4306	17157	3282	13627	8526	15654
34	12489	3386	16215	4474	14194	9919	15280
35	11250	3127	14859	3410	12303	9223	13708
36	11013	1933	13196	5884	11724	10183	12373

Table 9. Monthly and selected spring and fall weekly solar
          irradiance statistics.

MONTH	MEAN	STDEV	MAXIMUM	MINIMUM	MEDIAN	25%	75%
			--Logan--				
Mar	12754	5130	23161	2226	13320	8591	16891
Apr	18871	7159	29204	2930	19651	14307	25214
May	23068	7795	32211	3572	25558	15735	30063
June	26851	6378	34082	6167	28706	23727	31813
July	25876	5797	34938	8802	26826	23441	30253
Aug	25422	5328	34281	4722	26011	24345	28478
Sept	17821	6001	25188	720	20188	14507	22105
Oct	11621	4695	19858	1474	12800	8290	15223
Nov	7314	3472	13295	914	8148	4497	10175
Dec	5494	2437	9518	1085	5308	3453	7879
Jan	5652	2720	11340	1550	4773	3360	7993
Feb	10119	3923	17575	1350	10845	7228	12948

WEEK	MEAN	STDEV	MAXIMUM	MINIMUM	MEDIAN	25%	75%
1	11240	3974	18104	3983	10543	8414	14680
2	13562	5044	20497	2226	14275	10375	18313
3	11599	5616	21560	3106	10683	7926	16685
4	13863	5459	23161	3922	14222	9948	17987
5	13150	5554	21878	2930	14239	9749	16891
6	17723	6257	26488	4792	17932	12167	24031
7	23120	5100	28803	9787	25001	18463	27246
8	18416	8211	29204	3778	20762	10408	26130
9	20184	6091	28877	8374	20834	15697	25536
28	19291	5381	24075	7183	21708	18478	22761
29	20020	2844	22972	12764	21366	18881	22105
30	15611	6526	22521	720	18769	12141	20360
31	12474	6111	20649	3881	12378	6619	18901
32	14017	4138	18159	4909	16494	9766	17450
33	11230	4346	16847	1474	11406	8871	15464
34	12455	4131	16586	2595	14555	8290	14979
35	8682	4181	14870	1964	8993	4296	12255
36	9487	3063	13295	3277	9805	8168	12118

Table 10. Monthly and selected spring and fall weekly solar
          irradiance statistics.

MONTH	MEAN	STDEV	MAXIMUM	MINIMUM	MEDIAN	25%	75%
				--Lucin--			
Mar	15191	4724	22699	4158	15876	11831	18253
Apr	20167	6143	30214	2939	21028	16661	24477
May	24018	5888	32140	10976	24581	19548	29148
June	27432	5408	33714	11147	28861	25041	31950
July	26785	4959	33100	11537	28219	24760	30195
Aug	23228	4653	29701	9794	24517	20917	26267
Sep	18664	4867	25193	5005	20301	16552	22146
Oct	13460	3653	18637	3029	14817	10580	15947
Nov	9281	3044	13538	1934	9466	7637	11771
Dec	6916	2171	10791	2015	7321	5686	8696
Jan	6667	2835	12042	1175	6689	4493	9397
Feb	11208	3827	17022	5472	10907	7833	14065

WEEK	MEAN	STDEV	MAXIMUM	MINIMUM	MEDIAN	25%	75%
1	13396	4171	18402	4158	13817	9994	17035
2	14623	4192	19612	6266	13940	13391	17455
3	15686	5745	22699	9013	16350	9292	20415
4	15647	5600	22259	4924	17095	11799	19367
5	16089	4903	24477	2939	16433	13359	19225
6	21025	3841	25998	10857	20424	19241	23278
7	22374	6101	27824	6334	23421	18287	26912
8	20517	6704	28961	5932	21214	17985	17799
9	20223	5564	30214	10523	20827	16316	23954
28	18209	4872	24056	7428	18240	16154	21828
29	19861	3828	22664	5005	20981	19472	21760
30	17642	4384	22547	7474	19379	15248	20354
31	12531	4848	19075	6281	12818	9424	16895
32	13944	3986	18085	4251	14934	10557	17417
33	13549	3528	17423	5927	15249	11470	15932
34	14315	3447	16085	3029	15501	15028	15936
35	11638	3096	15063	5189	12288	9481	14460
36	11320	2080	13538	7688	11873	9358	13213
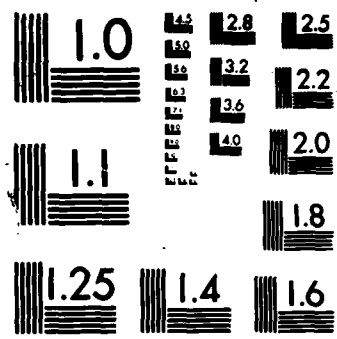
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Table 11.   Monthly and selected spring and fall weekly solar
            irradiance statistics.

MONTH	MEAN	STDEV	MAXIMUM	MINIMUM	MEDIAN	25%	75%
				--Salt Lake City--			
Mar	13566	5334	22392	2208	14742	9183	17988
Apr	20800	6530	29350	3613	22344	15655	26348
May	23695	7471	33329	5371	26012	18563	30206
June	27109	5569	33181	8504	29100	25224	31241
July	25608	5189	32434	1224	27326	22442	29520
Aug	22170	4645	28522	6114	23208	19442	25530
Sep	16609	5533	24364	1415	18931	14376	20312
Oct	12158	4257	18266	1667	13651	9000	15387
Nov	7712	3245	13537	1178	8118	5041	10439
Dec	5465	2483	10383	1057	5097	3571	7936
Jan	6128	2992	12454	1719	6328	3184	8534
Feb	10992	3745	17483	2635	11055	7762	13992

WEEK	MEAN	STDEV	MAXIMUM	MINIMUM	MEDIAN	25%	75%
1	11699	4972	18936	2665	11731	7453	16042
2	14713	4715	21336	4065	15552	12795	18631
3	13486	5970	22198	2968	14812	8155	18506
4	13220	5645	22392	2208	13539	9183	16891
5	16000	5767	23518	3613	17155	12027	20025
6	20547	5549	25779	7728	22428	18377	25399
7	22727	5600	28071	10713	26131	18936	26937
8	21214	7313	29350	7488	24106	17931	28067
9	20745	5814	28982	10990	20646	16959	25738
28	17342	5382	23642	3226	19147	15322	20997
29	18282	3162	21281	11273	20021	15848	20647
30	15477	5787	20312	1415	18647	11364	19904
31	12411	5462	19913	3360	13607	6820	18001
32	14207	4254	17885	3023	15861	12615	17289
33	11573	4190	16283	2344	12475	8448	15387
34	13018	3163	16119	5166	14686	10755	15236
35	9816	3973	14956	1667	10859	6099	13297
36	10575	2682	13537	3149	11916	8569	12633

Table 12. Monthly and selected spring and fall weekly solar
irradiance statistics.

MONTH	MEAN	STDEV	MAXIMUM	MINIMUM	MEDIAN	25%	75%
			--St. George--				
Mar	16491	5688	24865	3044	17551	12061	20869
Apr	23032	5893	28780	3865	25263	21561	26973
May	26429	5382	32069	8569	28671	23583	29928
June	28806	3965	32940	13358	30453	27078	31261
July	26637	4897	32018	9418	28692	23829	30403
Aug	23191	4702	29055	10388	25022	20563	26541
Sep	19250	4614	24513	4568	21022	17936	22107
Oct	15795	3338	19926	3921	16696	14598	18128
Nov	10413	3335	14973	858	11166	8530	12653
Dec	8197	2796	11774	1153	9273	6825	10275
Jan	9968	3074	13972	2243	11066	8118	12102
Feb	13193	3757	18756	3113	14331	11361	15681

WEEK	MEAN	STDEV	MAXIMUM	MINIMUM	MEDIAN	25%	75%
1	13684	5844	20869	3044	15378	8181	19079
2	16038	4388	20911	5837	17238	14849	19482
3	17270	5618	23635	4369	19720	12714	21833
4	18289	5983	23525	5115	21503	15011	22416
5	21234	5997	26305	3865	23593	16707	25085
6	21591	5980	27136	7157	24290	20281	25438
7	22728	6458	27672	9572	26288	18447	27031
8	24866	4884	28780	9641	26920	23049	27843
9	23223	5093	28616	7283	23616	21476	28033
28	20029	3845	23838	11235	21526	19112	23015
29	20917	2458	23491	14335	21804	20894	22434
30	17778	5120	22927	6672	19802	15252	21489
31	16039	5097	20904	4568	17718	14501	19874
32	18327	1539	19549	12883	18841	18030	19090
33	15955	2717	18742	9363	17091	15159	17720
34	14690	3457	17753	5733	16494	13326	16933
35	13290	3528	16335	3921	14652	13032	15110
36	12974	2171	14973	6845	13858	11885	14740

END

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